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Journal
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FIRST INTERNATIONAL ASTRONAUTICAL CONGRESS, PARIS, 1950

On October 7, 1950, two B.I.S. meetings were held which had their origin in the above event.

In the afternoon, a Council Meeting (attended by Messrs. Clarke, Gatland, Gillings, Humphries, Ross, Shepherd, Slater, Smith, Thompson and the Secretary) was held under the Chairmanship of Mr. A. V. Cleaver. At this, the results of the Paris Congress were discussed, and its final resolutions approved.

Although it is not our usual practice to report on Council discussions, we feel that the importance and general interest of the present occasion justify some statement to members. It was apparent that all the Council Members were strongly in favour of the new international federation of astronautical societies, providing that the autonomy of the existing national groups was preserved. It was felt that any attempt to go further than this, by forming a single international society, would be faced by so many administrative difficulties that it was impracticable for the present. This view had been previously expressed in Council, and had formed the basis of policy for the British delegation to Paris.

In the evening, the opening General Meeting of the 1950–51 session was held in the Tudor Room at Caxton Hall: 90 members and visitors were present. Mr. Cleaver was again in the Chair, and read his Report on the Paris Congress, as already published in the 1950 Annual Report (issued lst November). He amplified this with a few further explanations, and then invited the other British delegates to give their personal impressions.

Dr. Shepherd briefly described the French atomic pile at Châtillon, and expressed his pleasure at having attended an international conference which had actually *worked*. Mr. Clarke paid tribute to the interest of the exhibits at the Palais de la Découverte, and to the most impressive way in which they were displayed. He had visited this museum of science with M. Ananoff and some other delegates on October 3, while Messrs. Cleaver, Humphries and Shepherd had been to visit Dipl.-Ing. Rolf Engels at his home outside Paris; the exhibits included an astronautical section, in which there was a mock-up of the cabin of a man-carrying rocket. Mr. Humphries expressed admiration for Herr Engel's technical library and archives on rocket history; he also said that he believed the B.I.S. and the other larger societies could, and should, help the newer and smaller groups to establish themselves. This was one of the most important duties which the new federation could discharge.

Not all the remarks of the above three delegates (Mr. Burgess was unable to travel from Manchester to attend) were in such serious vein; all, however,

Scene in the foyer of the Richelieu Amphitheatre at the Sorbonne, before the public meeting on September 30 which opened the 1950 Paris Congress. Mr. Cleaver is seen being interviewed by some of the many journalists who attended; on his left is M. Ananoff (organiser of the Congress).

Another scene at the September 30 session with the journalists. Messrs. Clarke, Shepherd, Humphries and Burgess appear to have found something amusing in their talk with a representative of Britain's Kemsley Press. Dr. Schmiedl of Austria is behind (slightly above-right) Mr. Burgess.

supported Mr. Cleaver in his estimate of the success of the Congress, and all emphasised the efficient yet friendly atmosphere in which its business had been conducted.

The Chairman then invited contributions from the body of the hall, explaining that the Council were anxious to learn the feeling of the meeting and the general views of the membership. A most interesting discussion followed for the next hour, ranging from the proper functions of any astronautical society to the things which the new international federation could do, and including some consideration of how the interplanetary project might finally be financed.

The question was also raised of the finances of the federation; Mr. Carter (Secretary) agreed with Mr. Cleaver that this problem should develop only gradually, and for some time to come the individual member societies should each pay for the work they severally undertook on its behalf. The suggestion was made that the technical proceedings of the 1951 London Congress might be published as a book or pamphlet, also that the international federation should be a very valuable medium for public education in the ideas of astronautics.

A member asked why it was considered impracticable to form a single world astronautical society, with a British Branch, French and German Branches, etc. Mr. Cleaver replied on the lines explained in the above account of the preceding Council Meeting. The same member expressed the hope that the B.I.S. would do all in its power to aid those 1951 delegates who might experience currency and travel difficulties of the kind mentioned in the Paris report; Mr. Cleaver assured him that we would, and that an early exploration of the possibilities was intended.

Another member asked whether it was not possible that the non-participation of the Americans at Paris had been due to a feeling on their part that they were so far ahead of the rest of the world in rocket development that they had little to receive, only to give, from any project for international collaboration. Mr. Cleaver agreed that the United States were well in the lead in the field of practical rocket achievement, but did not think this explained the position. The difficulty so far in establishing close contact with the American Rocket Society had not been in connection with technical matters at all.

As far as exchange of technical data was concerned, this fell into two categories. In the first, where the Americans now lead, the governing consideration was national security, and information could be published only when officially cleared. It was not the wish of the B.I.S., any other European society, or the new federation, to interfere with any reasonable regulations on these matters. There was a second category, however, of purely interplanetary research, in which we should hope in future to be able to collaborate on a theoretical basis with the other European societies, and (if they were willing) with the Americans also. In answer to another questioner, Mr. Cleaver said he felt sure we could expect to see useful and interesting theoretical papers and design studies emanating from the other societies represented at Paris.

Mr. R. A. Smith said he believed all rocket engineers and scientists regretted the fact that, at the present time, almost all their work was directed towards military objectives, however unavoidable that situation might be. He believed

that, at some future time, it would be possible (and certainly most desirable) for those who held the great ideal of space-flight to make a great effort to turn the eyes of the authorities towards this more worthwhile objective. For that purpose, he was sure some international organisation would be necessary, and he hoped the meeting would express their gratitude to the British delegates to Paris, for their work in helping to lay the foundations for such a body. (Applause.)

A view of the October 1 working session. On the far side of the table and proceeding clockwise, we have: Dr. Brugel (Stuttgart G.f.W.), Herren Oesterwinter and Jungklaass (Hamburg G.f.W.), Mr. Humphries and Dr. Shepherd (B.I.S.), Mme. Fondere (interpreter), Ing. Hjertstrand (Sweden), Messrs. Cleaver, Burgess and Clarke (B.I.S.), Dr. Cap (Austria), Ing. Nebel (Germany), Dr. Sanger and Frau Dr. Bredt, Ing. Schmiedl and Dr. Ruckert (Austria), Senor Mur (Spain), Dr. Hansen (Denmark), and Prof. Tabanera (Argentine).

Mr. Cleaver thanked Mr. Smith for his spontaneous* remarks, and the meeting for the enthusiasm with which they had received them. He had intended, before closing the meeting, to ask formally from the Chair for the members' general approval of the action taken by the B.I.S. delegates in Paris, but it would now seem that that was superfluous. Observing that no speaker that evening had ventured any criticism of the agreements entered into, regarding the international federation of astronautical societies, Mr. Cleaver asked that if there were any present who did hold such dissenting views, they should now place them before the meeting.

There being no response to this invitation, the meeting was concluded very shortly afterwards, following a further brief discussion on general aspects of the evening's business.

* In subsequent conversation with Smith, we agreed that probably few people would find it easy to believe that his remarks *were* spontaneous! It happens to be quite true, however, that they were.—A. V. Cleaver.

ENTRY INTO CIRCULAR ORBITS—I

By Derek F. Lawden, M.A.

1. Introduction

The problem of the transfer of a body from the earth's surface into a circular orbit about our planet must now be regarded as the primary problem of astronautics. It seems probable that this problem can be solved using known chemical fuels and engineering techniques. A number of writers have emphasised the importance of building up a space station in this manner, orbiting around the earth, to be employed as a stepping stone to the Moon and planets and for numerous subsidiary purposes.[1,2,3] The time is therefore ripe for a theoretical discussion of the most suitable trajectory which might be employed along which to effect this transfer. Such a trajectory may evidently be divided into two arcs, (i) a relatively small arc immersed in the atmosphere, over which air resistance is a force of paramount importance and gravity may be assumed constant and (ii) a larger arc traversed *in vacuo*, over which all forces but those due to the attraction of the Earth and the jet thrust are negligible. The smaller arc presents the more difficult mathematical problem owing to the complicated nature of the air resistance function and the inadequacy of our knowledge regarding it. However, by approximating to this function by a mathematical expression of comparatively simple form and assuming that it will be decided to cleave the atmospheric film by the shortest possible route viz. by a vertical motion of the rocket, it should be possible to arrive at a value for the upward acceleration (assumed constant) which will permit the passage of a rocket from the Earth's surface to a point outside the atmosphere with a minimum expenditure of fuel. This problem will be examined along these lines in a later paper. This paper will be concerned with the arc of transfer from the terminal just outside the atmospheric belt to the circular orbit. It will be assumed that the initial velocity of the rocket is given and that it, and the terminal, lie in the plane of the orbit. The problem is therefore two dimensional. It will be further assumed that it is most advantageous to expend fuel rapidly at the beginning and end of the arc—at the beginning, to give the rocket sufficient momentum to carry it to the orbit, and at the end to match its velocity to the orbit. The writer is unable to prove a general theorem from which this assumption might be justified, but he is, none the less, reasonably convinced of its truth. Other types of transfer trajectories which have been suggested have been examined and in every case it has been possible to show that the fuel expended is greater than in the case of transfer by rapid initial and final thrusts.[4] The two periods of fuel consumption will be supposed small compared with the time of transit, so that the effect of gravitational attraction upon the velocity of the rocket will be supposed negligible during these periods. It will then follow that if the jet velocity be U and if $\mathbf{v}_0$, $\mathbf{v}_1$ be the vector velocities at the beginning and end of such a period respectively, then the ratio R of the masses of the rocket before and after the thrust is given by

$$U \log R = |\mathbf{v}_1 - \mathbf{v}_0| \quad \ldots\ldots\ldots\

that, at some future time, it would be possible (and certainly most desirable) for those who held the great ideal of space-flight to make a great effort to turn the eyes of the authorities towards this more worthwhile objective. For that purpose, he was sure some international organisation would be necessary, and he hoped the meeting would express their gratitude to the British delegates to Paris, for their work in helping to lay the foundations for such a body. (Applause.)

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$$U \log R = |\mathbf{v}_1 - \mathbf{v}_0| \quad \ldots\ldots\ldots\

it being supposed that the direction of thrust is maintained steady. In practice, extra fuel must be burnt to counterbalance gravity during these periods but there should be no difficulty in calculating this additional requirement and the slight variation in thrust direction which will be called for. The resulting trajectory will admittedly not then be the optimum, but will approximate very closely to it.

2. Mathematical Statement

In the diagram (Fig. 1), the inner circle represents the outer limit of the earth's atmosphere and the outer circle the circular orbit. α, β are the radii of these circles respectively. Initially the rocket is at A with velocity (u_0, v_0) resolved along the directions indicated. If the ascent through the atmosphere is vertical, we shall be able to assume that u_0 is equal to the Earth's velocity of rotation at the locality being considered.

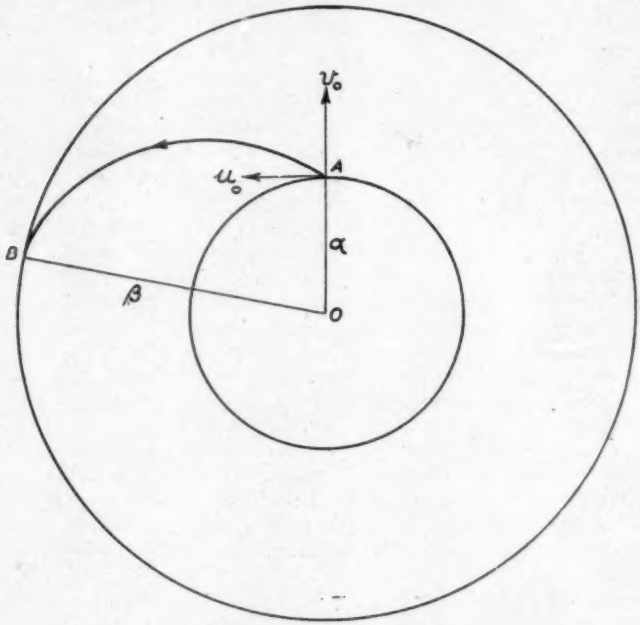

FIG. 1. The Transfer Orbit.

At A, fuel is burnt to change the rocket's velocity to (u_1, v_1), after which it coasts along the arc AB under its own momentum and the attraction of the Earth, arriving at the circular orbit at B. We shall show below that under optimum conditions the transfer orbit is tangential to the circular orbit, but this, though plausible, cannot be assumed to be obvious. At B fuel is burnt to align the rocket's velocity with that appropriate to the orbit.

Let μ/r^2 be the gravitational attraction per unit mass due to the Earth at a distance r from the centre. Consider a body orbiting about the Earth in any manner, so that its velocity when at a distance r from the centre is w. If the orbit be an ellipse of semi-major axis a, we have the fundamental energy equation

$$w^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right) \quad \text{.....(ii)}$$

In the case of a hyperbolic orbit $1/a$ is negative and in the case of a parabolic orbit $1/a = 0$.

If the velocity w may be resolved into components u, v perpendicular to and along the radius vector r, we have the equation of angular momentum

$$ur = \text{constant}, \quad \text{.....(iii)}$$

and the further equation

$$w^2 = u^2 + v^2 \quad \text{.....(iv)}$$

Applying these equations to the transfer trajectory AB we have first at A that

$$u_1^2 + v_1^2 = \mu\left(\frac{2}{\alpha} - \frac{1}{a}\right) \quad \text{.....(v)}$$

and then at B that

$$u_2^2 + v_2^2 = \mu\left(\frac{2}{\beta} - \frac{1}{a}\right) \quad \text{.....(vi)}$$

where (u_2, v_2) is the velocity of arrival at B, resolved in the manner already described.

(iii) also gives us

$$u_1\alpha = u_2\beta \quad \text{.....(vii)}$$

From (v)–(vii) it is easy to derive the results

$$u_2 = \frac{\alpha}{\beta}u_1 \quad \text{.....(viii)}$$

$$v_2^2 = \left(1 - \frac{\alpha^2}{\beta^2}\right)u_1^2 + v_1^2 + 2\mu\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) \quad \text{.....(ix)}$$

specifying the velocity of arrival in terms of the velocity of departure.

Now $v_2^2 \geqslant 0$, so that from (ix) we obtain the inequality

$$\left(1 - \frac{\alpha^2}{\beta^2}\right)u_1^2 + v_1^2 - 2\mu\left(\frac{1}{\alpha} - \frac{1}{\beta}\right) \geqslant 0 \quad \text{.....(x)}$$

Should (u_1, v_1) be selected so that this inequality is violated, v_2 becomes imaginary. The physical interpretation of this result is a failure of the trajectory to intersect the circular orbit. (u_1, v_1) are at our disposal, therefore, but must be chosen to satisfy (x).

Supposing then that (u_1, v_1) have been so chosen, we shall calculate the fuel expenditure corresponding to our choice and then vary (u_1, v_1) so as to minimise the fuel required.

The circular orbiting velocity at B is $\sqrt{(\mu/\beta)}$, so that in view of (i), the net mass ratio R necessary to achieve transfer is given by

$$U \log R = \sqrt{(u_1 - u_o)^2 + (v_1 - v_o)^2} + \sqrt{\left(u_2 - \left(\frac{\mu}{\beta}\right)^{\frac{1}{2}}\right)^2 + v_2^2}$$

and in view of (viii) and (ix) this is equivalent to

$$U \log R = \sqrt{(u_1 - u_o)^2 + (v_1 - v_o)^2} + \sqrt{u_1^2 - \frac{2\alpha}{\beta}\left(\frac{\mu}{\beta}\right)^{\frac{1}{2}} u_1 + v_1^2 - \mu\left(\frac{2}{\alpha} - \frac{3}{\beta}\right)} \quad \ldots\ldots\ldots\text{(xi)}$$

The mathematical problem is to minimise $U \log R$ subject to condition (x).

Before turning our attention to this problem, it is convenient to state the condition (x) and the equation (xi) in a dimensionless form. To this end we define dimensionless parameters x, y by the equations

$$u_1 = x\sqrt{\frac{\mu}{\alpha}}, \; v_1 = y\sqrt{\frac{\mu}{\alpha}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(xii)}$$

x being the fraction that u_1 is of the circular orbital velocity at A and similarly for y. x_o, y_o are then defined by

$$u_o = x_o\sqrt{\frac{\mu}{\alpha}}, \; v_o = y_o\sqrt{\frac{\mu}{\alpha}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(xiii)}$$

and r by

$$r = \frac{\alpha}{\beta} < 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(xiv)}$$

(x) and (xi) now become

$$(1 - r^2)\, x^2 + y^2 \geqslant 2\,(1 - r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(xv)}$$

$$\lambda = \sqrt{\frac{\alpha}{\mu}}\, U \log R = \sqrt{(x - x_o)^2 + (y - y_o)^2} + \sqrt{x^2 - 2r^{3/2}x + y^2 + 3r - 2} \quad \ldots\text{(xvi)}$$

respectively.

3. Mathematical Analysis

The first root on the right-hand side of (xvi) may be given a geometrical interpretation as the distance of the point (x, y) in the plane of rectangular cartesian axes Ox, Oy from the point (x_o, y_o). The second root may then be interpreted as the length of the tangent from the point (x, y) to the circle

$$x^2 + y^2 - 2r^{3/2}\,x + 3r - 2 = 0 \ldots\ldots\ldots\ldots\ldots\text{(xvii)}$$

Each curve $\lambda =$ constant is then the locus of a point which moves so that the sum of its distance from (x_o, y_o) and the length of the tangent from it to the circle (xvii) is constant. Such curves may be proved to be conics, and their layout in the two cases (*a*) when $(x_o y_o)$ lies within the circle (xvii) and (*b*) when $(x_o y_o)$ lies without this circle is shown in Fig. 2. The curves are restricted to lie outside the circle, since inside the circle the second root of (xvi) is imaginary.

The condition (xv) must also receive a geometrical interpretation. It is that the point (x, y) must be outside or on the ellipse

$$(1 - r^2)x^2 + y^2 = 2(1 - r) \ldots\ldots\ldots\ldots\ldots\text{(xviii)}$$

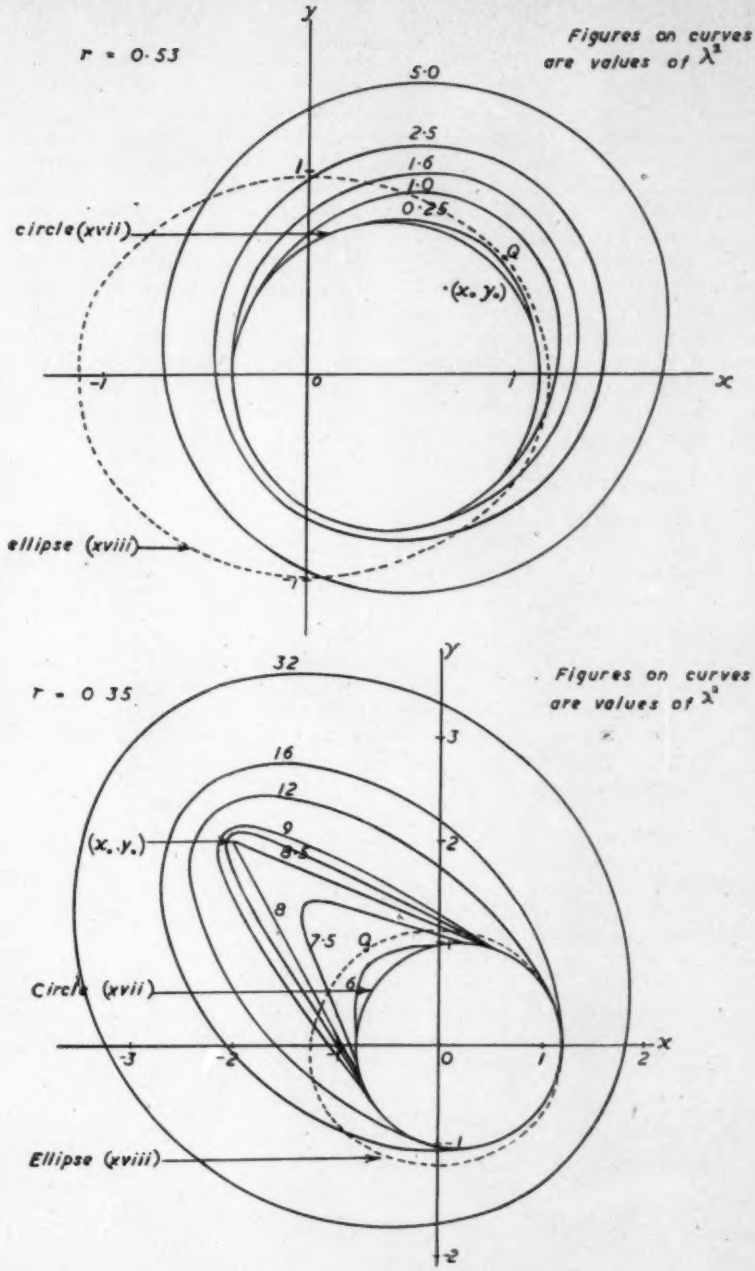

FIG. 2. Loci λ = constant.

It is easily shown that this ellipse invariably contains the circle within its interior, so that it will appear in our geometrical diagrams as shown in Fig. 2.

Our problem is therefore to find a point (x, y) in the diagram which lies outside the ellipse (xviii) and for which λ is as small as possible. By studying the curves $\lambda = \text{constant}$ it is easy to see that the point Q satisfies our requirement in either case. It should be observed that Q must lie on the ellipse (xviii) and from this fact we deduce that our solution (x, y) satisfies (xviii).

We have, therefore, reduced the problem to a minimisation of λ subject to (xviii), rather than the inequality (xv). The physical interpretation of this advance is that we now know that the optimum trajectory of transfer is tangential to the circular orbit. For if the equality sign be true in (x), then from (ix) we deduce that $v_2 = 0$, so that upon arrival at the circular orbit, the rocket's radial velocity is nil.

Substituting from (xviii) for y^2 in the second root of (xvi), we simplify the latter equation to the form

$$\lambda = \sqrt{(x - x_o)^2 + (y - y_o)^2} + r^{\frac{1}{2}} - rx \quad \ldots\ldots\ldots\ldots (xix)$$

it being apparent from (xviii) that $|x| < r^{-1}$.

There are two special cases which are easily dealt with and which will, therefore, first occupy our attention:—

(*a*) The case $y_o = 0$. In this case the rocket is moving initially parallel to the Earth's surface.

(*b*) The case $x_o = 0$. In this case the rocket is moving initially along a radius of the earth. Vertical ascent from either pole will result in this state of affairs, but vertical ascent from any other point on the Earth's surface will not, for a lateral component of velocity will be induced in the rocket due to the Earth's rotation and this cannot be considered negligible except in high latitudes.

4. The case $y_o = 0$.

(xix) now reduces to

$$\lambda = \sqrt{(x - x_o)^2 + y^2} + r^{\frac{1}{2}} - rx \quad \ldots\ldots\ldots\ldots\ldots\ldots (xx)$$

Substituting for y^2 from (xviii) we obtain

$$\lambda = \sqrt{r^2x^2 - 2x_ox + x_o^2 + 2 - 2r} + r^{\frac{1}{2}} - rx \quad \ldots\ldots\ldots (xxi)$$

Differentiating, it will be found that $d\lambda/dx$ is negative for all positive values of r, x_o and x. It follows that λ takes its least value when x takes its largest. Referring to (xviii) we observe that

$$x < \sqrt{\frac{2}{1 + r}}$$

so that λ is minimum when $x = \sqrt{2/(1 + r)}$. In this case we have

$$\lambda = (1 - r)\left(\frac{2}{1 + r}\right)^{\frac{1}{2}} + r^{\frac{1}{2}} - x_o$$

$$x = \sqrt{\left(\frac{2}{1+r}\right)} \qquad \text{(xxii)}$$

$$y = 0.$$

Interpreting these results physically, the rocket is accelerated along its initial line of motion until its momentum is sufficient to carry it along an elliptical trajectory, tangential to the given circular orbit.

Arriving at the latter orbit it is again accelerated along its line of motion until circular orbital speed has been achieved.

If $r = 0$, the rocket is required to escape to infinity and formulae (xxii) become

$$x = \sqrt{2},\ \lambda = \sqrt{2} - x_0$$

proving, as is well known, that the velocity of escape is $\sqrt{2}$ times the circular orbiting velocity.

A plot of the r-dependent part of λ in (xxii), viz.

$$(1-r)\left(\frac{2}{1+r}\right)^{\frac{1}{2}} + r^{\frac{1}{2}}$$

against r, is given in Fig. 3. It will be noted that as the radius of the circular orbit is increased, so that r decreases, the fuel requirement becomes larger and eventually, when the radius of the orbit exceeds the Earth's radius by a factor

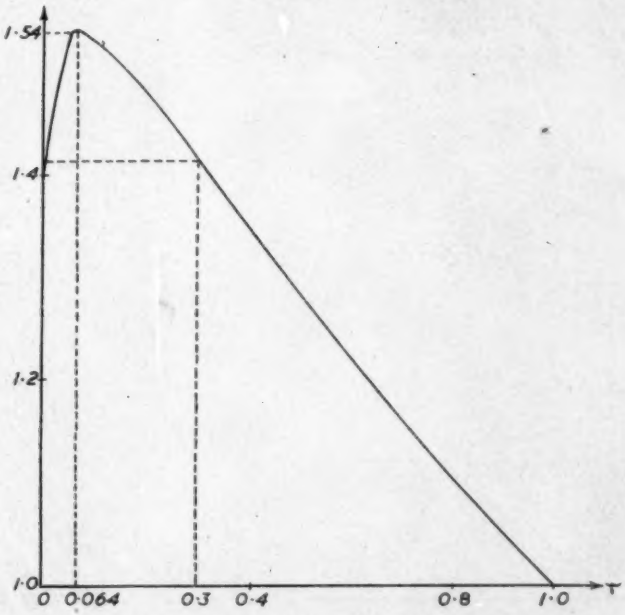

FIG. 3. Minimum λ as function of r when $y_0 = 0$.

of about 3 ($r = 0{\cdot}3$), the fuel requirement exceeds that necessary to achieve escape velocity. A circular orbit of radius 15·6 times that of the Earth, may only be achieved at the expense of $\lambda = 1{\cdot}54$, i.e. a net velocity increment of 1·09 times that necessary to escape to infinity from the Earth's surface.

Taking $U = 4$ km./sec., we can now plot mass ratio R against radius of circular orbit expressed as a multiple m of the Earth's radius (6,380 km.). The resulting graph for values of m from 1 to 6 is shown in Fig. 4, where we have taken $x_0 = 0$. The mass ratio corresponding to any other exhaust velocity U may be found by raising R to the power $4/U$. Thus, if the jet velocity be 2 km./sec., then the appropriate mass ratio is the square of that read from Fig. 4. The mass ratio necessary to effect direct escape from the Earth's surface using a jet velocity of 4 km./sec. is 16·5, and this is indicated in the figure. Since orbits of radii greater than three times the Earth's radius require mass ratios in excess of those necessary for direct escape, they are presumably of academic interest only.

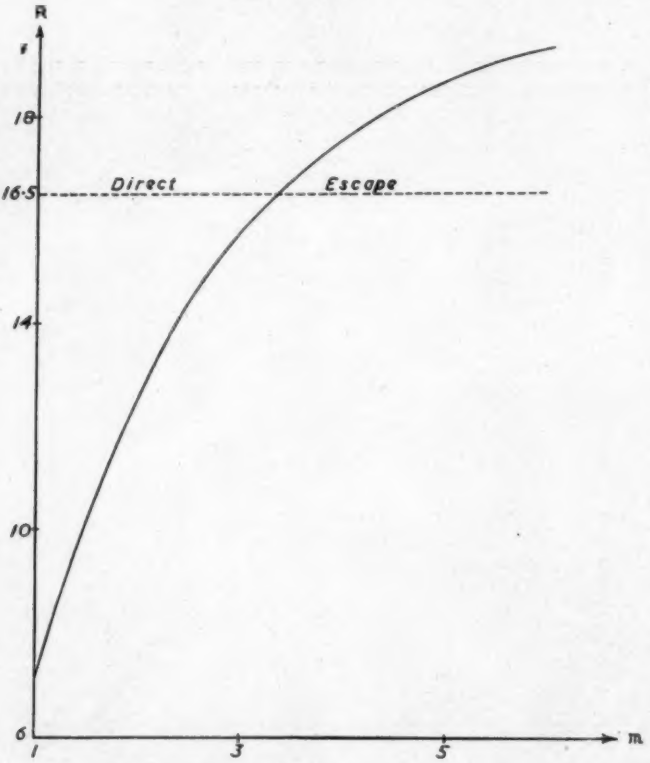

FIG. 4. Mass ratio for transfer when $x_0 = y_0 = 0$.

The mass ratio necessary to escape from the circular orbit to infinity is plotted against m for $U = 4$ km./sec. in Fig. 5. The formula used was

$$\log R = \frac{1}{U}\sqrt{\frac{\mu}{\alpha}}\left(\sqrt{\frac{2}{m}} - \sqrt{\frac{1}{m}}\right)$$
$$= 0{\cdot}82\, m^{-\frac{1}{2}} \quad \text{.....(xxiii)}$$

For any other exhaust velocity U, the figures for the mass ratio should be raised as before to a power $4/U$. It will be seen that these mass ratio figures are relatively small, even for circular orbits close to the earth, and should be attainable, even for large man-carrying rockets, without very great difficulty.

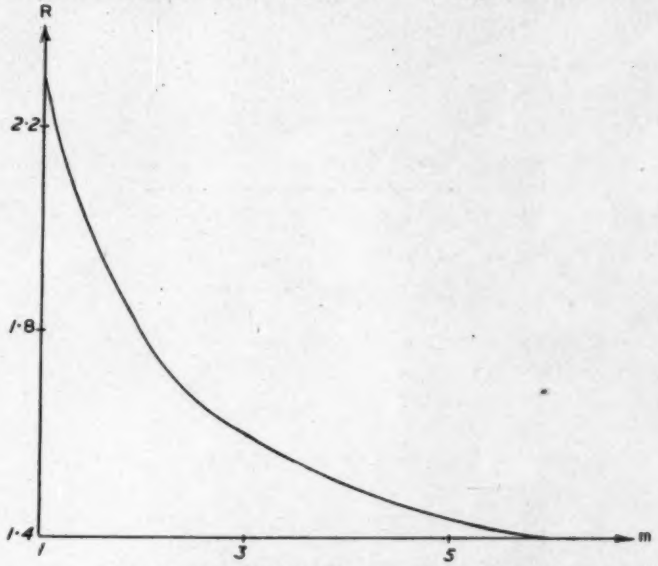

FIG. 5. Mass ratio for escape from circular orbit.

The same mass ratio figures give the fuel requirement for a manœuvre consisting of a free fall from infinity and tangential transfer to a circular orbit, so that even in the worst possible case of an orbit just outside the Earth's atmosphere, the net mass ratio for a manœuvre consisting of escape from the orbit, free orbit around the Moon under the dual attraction of Earth and Moon and return to Earth, and transfer to the circular orbit again, should not exceed a value of about 5·4.

The mass ratio requirement for a transfer from the earth terminal to the circular orbit is much greater, however, and is 8·0 for an orbit 400 miles above the Earth's surface. Allowance must further be made for the first phase of vertical ascent through the atmosphere and for the necessarily finite values of the accelerations which will be given to the rocket. We have taken x_0 to be

zero whereas in fact, at the Equator, its value will be about 0·06, so that this will tend to reduce the values of λ given above, if we suppose that our rocket will be possessed of this equatorial velocity initially. We cannot, therefore, at this stage of the investigation, assign a precise value to the mass ratio requirement for transfer into a circular orbit.

The mode of transfer we have been considering in this section is unlikely to be adopted in practice, since it makes no use of the considerable vertical component of velocity which the rocket will possess after passing through the atmosphere and consequently is by no means as economical of fuel. We shall now study a second extreme case which may be regarded as a close approximation to the practical case, viz. the case when the initial velocity is entirely vertical.

5. The case $x_o = 0$.

(xix) reduces to

$$\lambda = \sqrt{x^2 + (y - y_o)^2} + r^{\frac{1}{2}} - rx \quad \text{.....(xxiv)}$$

Substituting for x from (xviii) we obtain λ as a function of y, thus

$$\lambda = \sqrt{\frac{2}{1+r} + y_o^2 - 2y_o y - \frac{r^2}{1-r^2}y^2} + r^{\frac{1}{2}} - r\sqrt{\frac{2}{1+r} - \frac{1}{1-r^2}y^2} \quad \text{.....(xxv)}$$

Equating $d\lambda/dy$ to zero and solving the resulting quadratic, we find that λ is a minimum for

$$y = \frac{y_o(1-r^2)}{\{r^2 + \frac{1}{2}y_o^2(1+r)\}^{\frac{1}{2}} - r^2} \quad \text{.....(xxvi)}$$

The corresponding value of x is found from (xviii) to be

$$x = \sqrt{\frac{2}{1+r}} \cdot \frac{r\,|\,1 - \{r^2 + \frac{1}{2}y_o^2(1+r)\}^{\frac{1}{2}}\,|}{\{r^2 + \frac{1}{2}y_o^2(1+r)\}^{\frac{1}{2}} - r^2} \quad \text{.....(xxvii)}$$

Substitution of these values for x and y in (xxiv) gives for the value of λ,

$$\lambda = r^{\frac{1}{2}} + \left| \sqrt{\frac{2}{1+r}} - \sqrt{\frac{2r^2}{1+r} + y_o^2} \right| \quad \text{.....(xxviii)}$$

In practice y_o will usually be insufficiently large for the rocket to attain the circular orbit under its own momentum, unaided. Mathematically this is equivalent to the statement

$$y_o^2 < 2(1-r)$$

If this inequality be satisfied, the modulus signs in (xxvii) and (xxviii) may evidently be omitted, in which case (xxviii) reads

$$\lambda = r^{\frac{1}{2}} + \sqrt{\frac{2}{1+r}} - \sqrt{\frac{2r^2}{1+r} + y_o^2} \quad \text{.....(xxix)}$$

Putting $x_o = y_o$ in the corresonding result of (xxii), we find for the difference between the minimum $\lambda = \lambda_1$ corresponding to an initial velocity of y_o horizontally and the minimum $\lambda = \lambda_2$ corresponding to the same initial velocity vertically is given by

$$\lambda_2 - \lambda_1 = \left(\frac{2r^3}{1+r}\right)^{\frac{1}{2}} + y_o - \sqrt{\frac{2r^2}{1+r} + y_o^2}$$
$$\geqslant 0.$$

Thus a given initial speed is most advantageous if it is horizontal rather than vertical.

For variable y_o, λ, as given by (xxviii), is evidently smallest when the expression between the modulus signs is zero. This is the case when

$$y_o^2 = 2(1-r). \quad \ldots\ldots\ldots\ldots\ldots\ldots (xxx)$$

Then x and y as given by (xxvii) and (xxvi) are zero and y_o respectively. This is the case when the initial momentum of the rocket is just sufficient to carry it vertically to its circular orbit, when fuel is expended to give it orbital velocity. The fuel requirement is given by $\lambda = r^{\frac{1}{2}}$.

For given y_o and variable r, it may also be shown that λ as given by (xxviii) is a minimum when r is related to y_o as in (xxx). Our analysis, therefore, suggests that r should be chosen, after y_o has been calculated from other considerations, to satisfy (xxx) and that the rocket should be allowed to coast vertically under its own momentum to a standstill and then be given circular orbital velocity.

y_o and r will generally both be specified, however, and then the optimum solution is given by equations (xxvi)–(xxviii).

6. The General Case.

We have now to find the conditions under which λ, as given by (xix), is a minimum subject to condition (xviii). Equating $d\lambda/dx$ to zero we arrive, after rationalisation, at a fourth order equation in either x or y. The appropriate root of this equation cannot be expressed in a form suitable for calculation. It is therefore more expedient to calculate numerically, direct from (xviii) and (xix), the values of x, y, λ required in any particular case, when the values of x_o, y_o and r are given. A first approximation to the value of λ we are seeking may be obtained by plotting λ as a function of x or y and determining the minimum by inspection. This approximation may be improved if desired by means of an iterative procedure which we shall now describe. Setting $d\lambda/dx$ equal to zero and using (xix), we obtain

$$(1-r^2)y_o x = (r\lambda - r^{3/2} + x_o)y.$$

Eliminating x by use of (xviii) we find that at the minimum of λ we have

$$y^2 = \frac{2(1-r)(1-r^2)y_o^2}{(r\lambda - r^{3/2} + x_o)^2 + (1-r^2)y_o^2} \quad \ldots\ldots\ldots\ldots (xxxi)$$

Substitution of a first approximate value of λ in (xxxi) gives us an approximation to y and then (xviii) supplies us with an approximation to x. By substitution of these values for x and y in (xix) we obtain a better approximation to λ, which can now be set into (xxxi) and the process repeated. We continue in this manner until no difference in the values of x, y, λ is found between one stage and the next, to the degree of accuracy to which we are working.

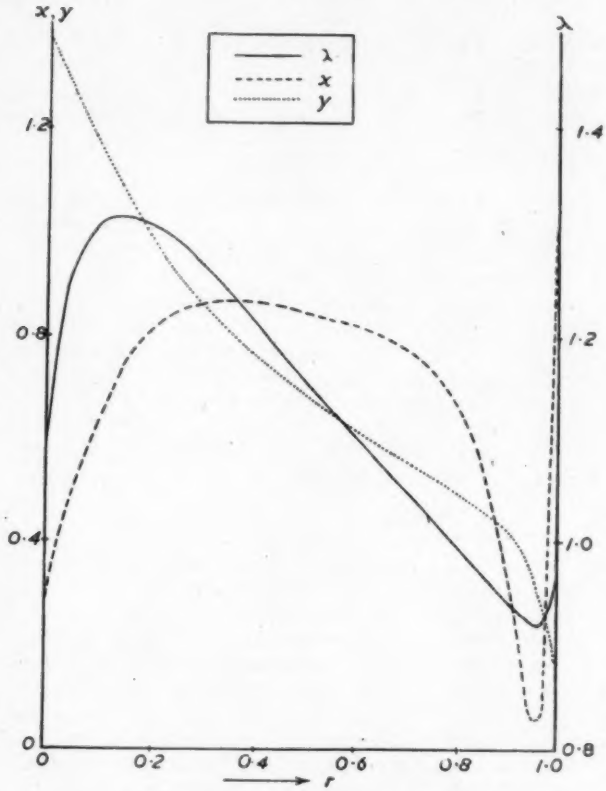

FIG. 6. Optimum values of x, y, λ when $x_0 = 0{\cdot}06$, $y_0 = 0{\cdot}3$.

To illustrate the method, we have selected the particular case $x_0 = 0{\cdot}06$, $y_0 = 0{\cdot}3$. These figures correspond to the case of a rocket which ascends vertically from the Equator with steady acceleration 2 g. to a height of 100 miles, when it is considered to have arrived at the terminal of the transfer trajectory.

Taking $r = 0{\cdot}4$ we obtain the table below:

x	y	λ
0·2	1·080	1·35
0·4	1·033	1·28
0·6	0·947	1·24
0·8	0·814	1·21
1·0	0·600	1·22
1·2	0	1·33

by use of (xviii) and (xix) alone. It is evident without graphing that $\lambda = 1{\cdot}21$ is a suitable first approximation. Substitution in (xxxi) gives $y = 0{\cdot}7656$ and hence $x = 0{\cdot}8551$. From (xix) we now calculate as a better approximation to λ, $\lambda = 1{\cdot}212$ and using this value in (xxxi) we obtain the value of y as 0·7643 and the corresponding value of x as 0·8563. Substituting these values in (xix) we obtain $\lambda = 1{\cdot}212$ as before, so that the process has converged.

Letting r take a number of values over the range $0 \leqslant r \leqslant 1$ and finding the corresponding optimum values of x, y and λ by the above method, we obtained data from which the graphs of Fig. 6 have been constructed. It will be observed that for values of r less than 0·6, the fuel requirement is greater than it is to achieve escape (the case $r = 0$), there being a maximum fuel expenditure in the case $r \doteqdot 0{\cdot}2$. This phenomenon has already been observed in section 4 above. The fuel requirement is a minimum when the orbit selected is tangential to the trajectory traced out by the rocket if allowed to proceed under its own momentum from the Earth terminal.

There is no point at this stage of the investigation in performing more detailed calculations of this character for ranges of values of x_0, y_0 and r. The next stage is to turn our attention to the initial part of the rocket's trajectory which lies in the Earth's atmosphere. This investigation should suggest the values of x_0 and y_0 which are likely to be useful in practice. Knowing these values, the above method will permit us to find the most suitable transfer trajectory along which to bring the rocket into a required circular orbit.

REFERENCES

(1) H. E. Ross, "Orbital Bases," *J.B.I.S.*, January, 1949.
(2) K. W. Gatland, "Rockets in Circular Orbits," *J.B.I.S.*, March, 1949.
(3) Willy Ley, "Rockets and Space Travel," Chapter 12.
(4) D. F. Lawden, "Note on a Paper by G. F. Forbes," *J.B.I.S.*, September, 1950.

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POPULAR ASTRONOMY

CARLETON COLLEGE, NORTHFIELD, MINNESOTA, U.S.A.

THE EARTH'S ATMOSPHERE

By J. Humphries, B.Sc.(Eng.), A.M.I.Mech.E., A.F.R Ae.S.

(*A paper read to the British Interplanetary Society in London on November* 4, 1950.)

Introduction

In 1714, according to Edmund Halley:—"The theory of the air seems now to be perfectly well understood, and its different densities at all altitudes, both by reason and experiment, are sufficiently defined." His conception of the atmosphere was that it was 45 miles high and that the air became steadily thinner and colder toward the top until it merged into outer space.

Almost two hundred years were to pass before much further interest was taken in investigating the atmosphere. Since the beginning of the present century a vast number of papers have appeared in journals scattered all over the world. The most comprehensive survey of upper atmosphere information of the pre-rocket-sonde era is *The Upper Atmosphere* by Mitra. Since this book was published, direct measurements have been made by means of rocket-sondes to altitudes of over 100 miles and our stock of knowledge has been vastly increased. We now realise that there are many more gaps in our knowledge waiting to be filled than have already been filled.

At present an army of scientists, mainly in the U.S.A., is engaged in an intensive investigation of the upper atmosphere and a huge array of equipment is being used. Much of the interest must be of a purely military nature, as the long-range missiles at present under development call for an accurate knowledge of upper atmosphere conditions. Consequently, colossal sums are being expended on firing lavishly equipped high-altitude rockets and—more power to the U.S. Government's elbow—much of the resulting knowledge is being released. The result is a flow of information which, combined with papers from other sources, is almost overwhelming. In a short paper it is essential to concentrate on one small facet of the subject. Fortunately, there is one topic in which our Society is particularly interested; that is the properties, particularly of the higher regions, which would affect the entry of a spaceship or other projectile into the atmosphere, or affect the motion of an artificial satellite. These properties are density, temperature and composition. There are many other phenomena of interest, perhaps in the future of vital interest to the astronaut, but at present they must be passed by.

I shall start with a very brief review of the general structure of the atmosphere, to get things in their correct perspective, then devote the bulk of the paper to those properties already mentioned. Space, unfortunately, will not permit detailed discussion of the methods of measurement—a subject as important as the measurements themselves.

General Review

The atmosphere can conveniently be divided into four parts, the troposphere, the stratosphere, the ionosphere and the exosphere. These layers are not marked by any sharp changes in characteristics. They are regions characterised

by certain physical features merging one with another. It is quite likely that as more is learnt about the atmosphere these regions will have to be redefined or subdivided.

The troposphere is the lowest of the four and ranges in height from about 10 miles at the Equator to 5 miles at the poles. Although comparatively small in volume it contains approximately three-quarters of the total weight of the atmosphere. It is the most clearly defined of the layers and is characterised by decreasing pressure and temperature with increasing altitude. The air in it is very much stirred up and its gaseous components consequently in very constant proportions. It is within the troposphere that all of the Earth's weather disturbances are created.

From the tropopause, which is the name given to the uppermost limit of the troposphere, the stratosphere extends upwards to a height of about 50 miles. It contains slightly less than one-quarter of the weight of the atmosphere and is characterised by a temperature distribution which, with increasing altitude, is at first constant, then increases to a maximum and then decreases. The maximum temperature occurs in the concentrated region of ozone which is known as the ozonosphere.

The ionosphere's upper and lower limits are subject to large daily and seasonal variations. It is characterised by the presence of ions and free electrons and was discovered by Kenelly and Heaviside when studying reflected radio waves. It contains only three-thousandths of the weight of the atmosphere. Generally speaking the degree of ionisation increases with altitude although it passes through consecutive "maxima" known as the D, E, F_1, and F_2 layers. The temperature increases continuously from about 270° K. at the top of the stratosphere to about 2500° K. at the top of the ionosphere.

The exosphere or "fringe" region stretches onwards to the outer limits of the atmosphere and contains but one 10,000 millionth of the total weight. The lower limit is not accurately known but may be between 300 and 600 miles. In this layer the number of particles in a unit volume is so small and the mean free path so great that particles reach very high velocities and consequently high temperatures may be experienced—of the order of 10,000° K. However, since matter is extremely diffuse at these altitudes the heat content is negligible and temperature becomes rather an academic term. Some of these particles rise to great heights in free flight before returning under Earth's gravity and a few of them reach escape velocity never to return to the atmosphere.

Methods of Investigation

Before concentrating on the properties of particular interest it may be as well to look briefly at the various methods which have been used in the investigation of the atmosphere.

(*a*) Direct measurement. Up to the end of the nineteenth century all measurements obtained had been from manned balloons and it was not until 1892 that unmanned instrument-carrying balloons were used. This extended the range to 25 miles, which was the limit before the coming of rocket-sondes. The maximum altitude is now 250 miles. Data obtained from these sources include temperature, pressure, wind drift and composition. Aircraft also have

played a leading part in building up our knowledge of the atmosphere up to an altitude of about 45,000 ft. and their importance in, for example, weather forecasting cannot be over emphasised. (0–250 miles.)

(*b*) Spectroscopic studies of the sun and night sky light help in composition determination. The solar spectrum is found to end abruptly at about λ2900Å. This is due to absorption of the ultra-violet by atmospheric ozone, and a critical study of the solar spectrum by direct light and by light scattered from the zenith sky has given information on the distribution of ozone in the middle atmosphere. (10–40 miles.)

(*c*) The study of abnormal sounds is very important historically as this line of investigation did more than any other to break down belief in the atmosphere as pictured by Halley. Peculiarly enough Queen Victoria's funeral played an important part in this little bit of research. In 1901 "minute guns" were fired in London as part of the funeral rites and the sound of these was alternately audible and inaudible in concentric rings around the source. After numerous theories had been propounded and proved wrong the theory that a high-temperature exists at the 20 to 40 mile level was proposed and generally accepted. The phenomenon is caused by the refraction of the sound waves by the high-temperature layer. A number of planned explosions have since taken place—the largest in Heligoland in 1947—and temperatures so obtained up to about 100 miles. (25–100 miles.)

(*d*) The radar and phototheodolite tracking of meteors and their trails and a study of the altitudes at which they appear and disappear have established temperatures, densities and winds in the region where they are visible. (25–150 miles.)

(*e*) Noctilucent clouds are rare night clouds which are illuminated by the sun's rays from below the horizon. Studies of these have given wind velocities. (40–60 miles.)

(*f*) Careful analysis has shown that besides the normal erratic variations there are regular variations in both barometric pressure and terrestrial magnetic elements. There exist world-wide daily and twice daily pressure oscillations. Study of these has shown that besides periodic heating and cooling of the atmosphere there exists a world-wide wind-system in the upper atmosphere caused by the tide-raising forces of the sun. The terrestrial magnetic elements are found to undergo small but regular daily and seasonal variations. These yield data regarding the electrical conductivity of the ionised regions. (50–70 miles.)

(*g*) Study of the reflection and absorption of radio waves has taught us much of the structure of the ionosphere and its variation in altitude with time of day, season and latitude. (50–300 miles.)

(*h*) A large proportion of the light emitted by portions of the sky on dark moonless nights is emitted in the process of neutralisation of the charged particles in the ionosphere. Spectral and other studies of this phenomenon have given information regarding the constituent gases, their distribution and temperature. (100–300 miles.)

(*i*) Auroral streamers extend to great heights and study of the spectra and heights of occurrence gives information regarding the nature and distribution of the gases. (50–600 miles.)

(*j*) Theoretical study of the escape of molecules from the Earth shows that the atmosphere is topped by a fringe of particles in free flight. (500 miles outward.)

Detailed Survey of Density, Temperature and Composition

As I have just indicated, our knowledge of the properties of the atmosphere lessens with altitude. For the troposphere we possess a wealth of information, particularly with regard to temperatures, pressures and composition, although the region is so complex that it would be unwise to say that we fully understand it. The lower stratosphere up to balloon-sonde limits is also quite well known but from there on our knowledge is more scanty. Fortunately the gaps are now being filled in by direct measurement up to altitudes of over 100 miles, i.e. well into the lower ionosphere, but from there on all our knowledge has been obtained by indirect observation or theory.

I will deal with composition first. For the troposphere 99·99 per cent. of dry air is composed of the four gases, nitrogen, oxygen, argon and carbon dioxide. These are in the proportions nitrogen 78·09 per cent., oxygen 20·95 per cent., argon 0·93 per cent. and carbon dioxide 0·03 per cent. The other 0·01 per cent. is made up of neon, helium, krypton, hydrogen, xenon, radon and ozone. Other components of the air, however, vary widely. For example, water vapour varies from 4 per cent. over tropical oceans to 0·05 per cent. or less at the top of the troposphere. The principal ingredients of the higher atmosphere are still nitrogen and oxygen but there are important changes in the rarer gases. For example, radon, which is a product of the decomposition of radium, originates from radio-active rocks. It is the heaviest of the atmospheric gases and tends to settle at the bottom of the atmosphere. It is also radioactive and is apt to disintegrate before it can be carried up to the higher levels—hence it has never been found in the upper atmosphere. Ozone, on the other hand, originates in the lower stratosphere where it is formed by the action of ultra-violet light on molecular oxygen. Ozone, therefore, is relatively rare in the troposphere but increases in abundance with altitude reaching a maximum in the region of 20–40 miles altitude. If all the ozone in the atmosphere were concentrated in one pure layer at sea-level pressure it would be only about one-tenth of an inch thick. Yet this small amount is extremely important as ozone is a powerful absorber of the sun's ultra-violet radiation. Consequently the ozone layer heats the stratosphere to much higher temperatures than the troposphere. It is known then that the composition of the atmosphere is fairly constant throughout the troposphere, stratosphere and lower ionosphere, that is, mainly oxygen and nitrogen.

The composition of the upper ionosphere and exosphere is, however, still open to considerable doubt, only indirect measurements and theory being able to guide us. (See Fig. 1.) The great height of the atmosphere tends to make one think that its upper levels consist either of very light or very hot gases.

One theory is that it consists of hydrogen and helium. The presence of helium in large quantities would certainly account for the great height of the atmosphere and much effort has been expended in trying to detect it. Absorption spectra of the upper air show no sign of it, but this is not conclusive as other known constituents, notably nitrogen, also fail to produce absorption spectra. Emission spectra have given more definite information. They are obtained from auroras and the faint light given off by the night sky. Both these sources show abundant evidence of nitrogen and oxygen but no sign of helium. These observations do not, of course, completely rule out the existence of helium, but are pretty strong evidence of its non-existence up to 500 miles altitude.

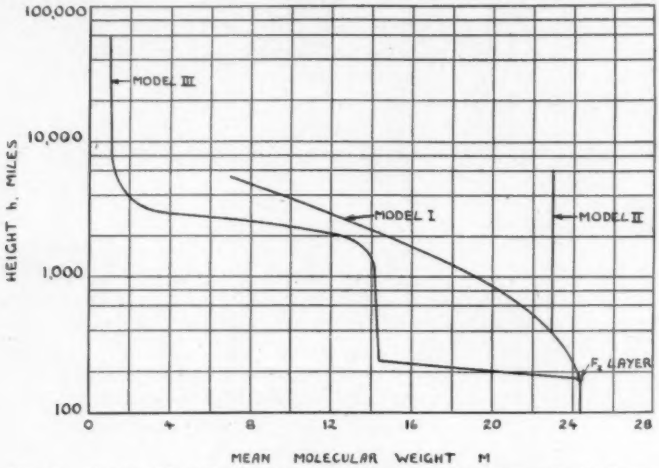


FIG. 1. Vertical distribution of mean molecular weight above the F_2 layer at latitude 45°.

That being the case the question arises as to what has become of the helium that has been fed into the atmosphere by the break-up of radioactive rocks during geological time. It has been estimated that during its lifetime the Earth's crust has released more than 12 times as much helium as now exists in the atmosphere, even assuming that above 500 miles nothing but pure helium exists. As helium is inert and cannot combine with other atmospheric constituents the only possible answer is that it must have escaped into space. It can be calculated that for this rate of loss a temperature of over 1000° K. would be necessary. Hydrogen being lighter would escape much more rapidly and the likelihood of this remaining in the upper atmosphere seems remote.

The composition up to the ozonosphere is then fairly well established. Above this both oxygen and nitrogen still form the major part of the atmosphere —oxygen in the atomic form, nitrogen in the molecular form until the upper ionosphere is reached when perhaps there is some dissociation. As for the exosphere all that can be made are estimates. According to Grimminger[2] there are nine possible states of the atmosphere at its outer limit ranging from

completely dissociated and ionised hydrogen with a mean molecular weight of $\frac{1}{2}$ to dissociated but non-ionised nitrogen with a mean molecular weight of 14. These are extremely wide limits and I shall return to these compositions in more detail later when considering Grimminger's atmosphere models.

Again with temperature our knowledge is soundly based on measurements from balloon and rocket-sondes up to about 75 miles. (See Fig. 2.) In the

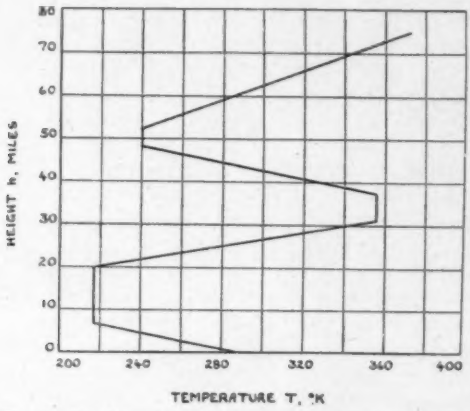


FIG. 2. Vertical distribution of temperature at latitude 45° from sea level up to 75 miles.

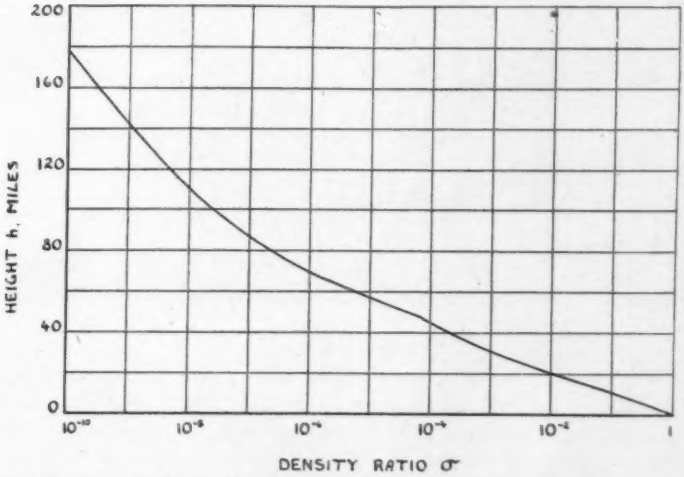


FIG. 3. Vertical distribution of the density ratio σ from sea level up to the F_2 layer at latitude 45°.

troposphere there is a steady fall in temperature, while in the lower part of the stratosphere it is constant, rising again to a maximum in the ozonosphere before once more falling to a minimum. In the ionosphere the temperature rises steadily and we have every reason to believe that this rise continues up to the F_2 layer at about 190 miles where a temperature of 1,000° K. is reached. Past the F_2 layer one can only make suggestions as to the possible temperature distribution and again I will leave these until I deal with the Grimminger models.

There is little to say about the pressure and density variations up to the F_2 layer as these also are reasonably well known. Fig. 3 shows variation of the density ratio for mean conditions at latitude 45°. Appreciable daily variations of temperature do occur which, of course, affect the density, but in order to keep the length of the paper within reasonable limits I do not intend to deal with them.

Finally, I will briefly review Grimminger's three models of the upper atmosphere. These are three preliminary studies of the atmosphere above the F_2 region made to discover what sort of conditions would exist if certain simplifying assumptions were made.

The way to tackle this job is to find out first what is known about the limiting regions and then, making the simplest assumptions possible, to calculate the various properties of this theoretical atmosphere and decide whether they are reasonable or not and if they can be improved upon. The lower boundary is the F_2 region which, as we have seen, has a temperature of about 1,000° K. The other boundary, interplanetary gas, is thought by some authorities to have a kinetic temperature of 10,000° K. A form of temperature variation is

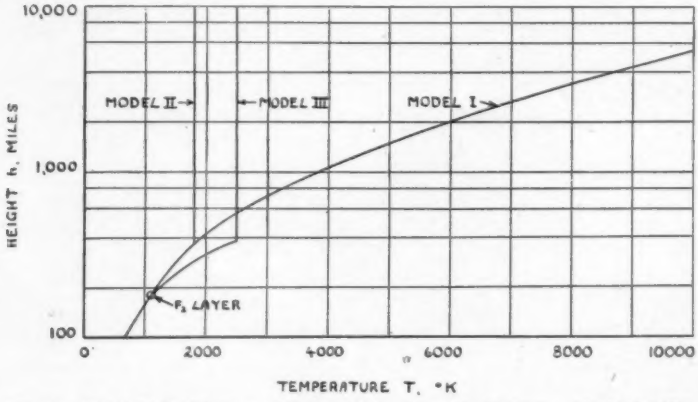


FIG. 4. Vertical distribution of temperature above the F_2 layer at latitude 45°.

assumed which simplifies the calculations. (See Fig. 4.) With regard to the composition which has already to some extent been dealt with, it is assumed that this will vary with height. In this instance an atmosphere of completely dissociated oxygen and nitrogen with a mean molecular weight of 15 is assumed at the F_2 layer and a mean molecular weight of 7 for the outer boundary, this

being half-way between the possible limiting values. A variation of mean molecular weight of a form similar to that of the variation of temperature is assumed. (See Fig. 1.)

One major drawback of Model I, just described, is the assumption that the atmosphere is a continuum above the F_2 layer. It is more acceptable from many points of view to treat the exosphere on the basis of the existence of a dynamical orbit region composed of particles moving essentially in free flight in the gravity field. Thus a particle moving upward in this region would find so few particles above it, that if it were moving with escape velocity it would stand a very good chance of escaping from the Earth entirely without hitting another particle. It is further assumed that the interplanetary gas has no effect

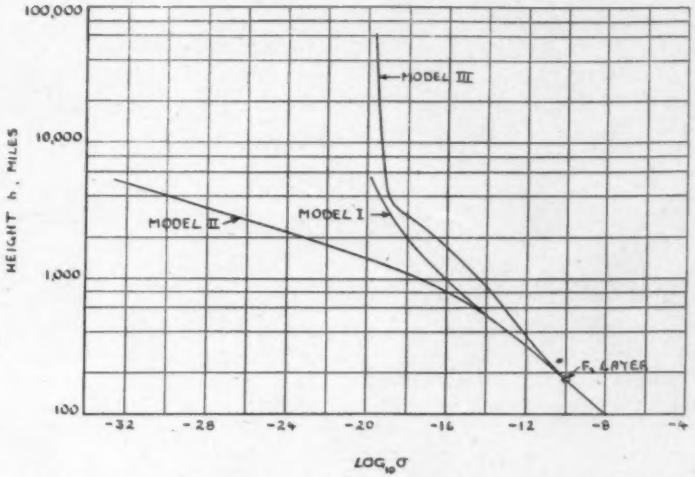


FIG. 5. Vertical distribution of the density ratio σ above the F_2 layer at latitude 45°.

upon the atmosphere, and since the atmospheric particles themselves do not collide the region must, according to Spitzer, be isothermal. The exosphere is calculated to begin at about 550 miles and to have a temperature of 2,000° K. The density is assumed to follow Boltzmann's law for distribution in an isothermal atmosphere, all particles are assumed to be neutral, and the mean molecular weight taken to be constant.

In this model no account is taken of diffusion equilibrium and the temperature at the beginning of the exosphere is calculated from the results of Model I. Model III is a refinement of Model II in that diffusion equilibrium in the upper ionosphere and exosphere is considered and the temperatures more closely investigated, and is the most acceptable of the three models. The temperature of the exosphere in this case is taken as 2,500° K. The variation of the density ratio for the various models is given in Fig. 5.

Conclusions

And that, very roughly, is the state of our knowledge at present. Our knowledge of conditions up to the F_2 layer is quite accurate enough for our purposes, at any rate for preliminary calculations of entry orbits. I do not think, for entry orbits at least, that we shall be very interested in conditions above this height. For stability of artificial satellites we may be interested.

REFERENCES

(1) S. K. Mitra, *The Upper Atmosphere.* The Royal Asiatic Society of Bengal, Monograph Series, Vol. V, Calcutta, India, 1948.

(2) G. Grimminger, *Analysis of Temperature, Pressure and Density of the Atmosphere Extending to Extreme Altitudes,* U.S. Air Force Project, RAND Report, No. R-105, The RAND Corporation, Nov. 1, 1948.

(3) G. P. Kuiper (Ed.), *The Atmospheres of the Earth and Planets,* University of Chicago Press, 1949.

(4) H. E. Roberts, "The Earth's Atmosphere," *Aero. Engng. Rev.*, Oct., 1949.

PROBLEMS OF MISSILES ENTERING THE ATMOSPHERE

BY T. NONWEILER, B.Sc.

(*A paper read to the British Interplanetary Society in London on November* 4, 1950.)

I don't know who the unwitting optimist was who first stated that "What goes up, must come down" but in these more enlightened days we have good reason to doubt that gentleman's credentials. Even supposing that the space-ships of future time appear to obey this rule, the process of "coming down" is looked upon with a certain misgiving. A widespread opinion, I believe, is that the Earth's atmosphere is an embarrassment to this process, being insufficient to afford any appropriate retardation yet not so tenuous that frictional heating may be negligible; an opinion which is borne out by the ugly fate of meteors, large and small, entering our atmosphere! As a consequence it is usually supposed that a space-ship making the return journey must destroy its energy by the same mechanism as it was derived.

But I hope to suggest that such a measure—with all its implied complications—is unnecessary, because the atmosphere can provide the required retardation without introducing any insuperable difficulties. Certainly, at such a time as this it is impossible to do more than "suggest" the result. There are so many unknowns involved and the intended scope of this discussion so broad that only a few simple ideas can be used to illustrate the problems involved.

The real problem lies in the implications of the retardation process, for clearly there is no problem involved in the assertion that the air *can* provide sufficient deceleration. For, to quote a simple example: let us assume that a missile falls from rest "at infinity" in the Earth's gravitational field, and that the air resistance varies as the air density—calculated by assuming the atmosphere to be isothermal, as in the stratosphere—and as the square of the missile's velocity. This last-mentioned assumption is reasonable enough if applied to

a body of revolution travelling at very high speeds. We may then estimate the missile's velocity of impact at the Earth's surface as a function of the ratio:—

$$\frac{D}{W} = \frac{\text{Drag at speed of sound at sea-level}}{\text{Missile weight}}$$

The results of such calculations are shown in the following Table.

D/W	3	5	10	30	100	300	1,000	3,000
Velocity of impact, ft./sec. ..	8,300	3,100	460	210	120	67	37	21
Retardation prior to impact ..	$-180\,g$	$-38\,g$	$-0{\cdot}7\,g$	negligible				

For the larger values of D/W, almost all the kinetic energy of the missile has been destroyed in the upper parts of the atmosphere. It is worth noting that values of D/W of the order of 1 are typical of slender projectiles, whereas values between about 30 and 100 apply to hollow metal spheres and the like, and that higher values would necessitate the use of some form of parachute. If, as seems most likely, the missile were in fact the smallest component of a large step-rocket, the large drag of this last stage would not cause any appreciable loss in speed during the ascent.

In deference to public opinion, and to facilitate the identification, location and recovery of the missile, a low impact speed—say, about 30 ft./sec.—would be desirable, if not essential. A glance at the above table will suggest that there are two methods of achieving such a low speed: the missile may be designed so that its drag is such that D/W is about 10, in which event its speed of descent at low altitudes is sufficiently small to allow the use of conventional-type parachutes to effect the necessary retardation in the last few thousand feet of the descent; or alternatively, the payload of the missile could make the entire entry and descent into the Earth's atmosphere beneath some extensive "drag-canopy," which might provide a drag such that D/W would be about 1,000 and which would obviate the need for any additional braking device for use just before impact.

I use the term "drag-canopy" advisedly, as no ordinary parachute would withstand the rigours of the descent. The maximum deceleration suffered is as large as 370 g occurring at a height where the air pressure relative to that at sea-level is equal to the ratio W/D, (i.e. at a height of about 30 miles), and where the speed of descent is about 60 per cent. of the escape velocity. We may therefore infer that the maximum air pressure on the canopy is about

$$\frac{W}{D} \times 10^6 \text{ lb./sq. ft.}$$

This value of the maximum retardation is the same for all forms of "free-fall" into the atmosphere, and it would not seem very likely that the instruments carried would withstand it, unless there had been special attention to their design.

Another problem concerns the possibility of stabilising the missile *aerodynamically* during descent so that these high loads would be localised. Gyroscopic stabilisation might well be necessary to ensure that the missile enters the atmosphere with the correct orientation of its axes to its direction of motion, as by this means the chief cause of instability at high altitude would be avoided. Such gyroscopic stabilisation might be necessary, of course, for other reasons.

It is worth noting in passing that the high decelerations occur at heights where it is still appropriate to suppose that the air is a continuum. There are four states of air flow to be considered[1]: let δ be the boundary layer thickness, and l the molecular free path. Then, very roughly,

(i) if $l/\delta < 0{\cdot}01$, the air acts as a continuum;

(ii) if l/δ is between 0·01 and 1, the air no longer "sticks" but *slips* at the body surface;

(iii) if $l/\delta > 10$, the air acts as a discontinuous medium obeying the laws of "free molecule flow."

There is a transition state between those marked (ii) and (iii).

In the present case, assuming that the characteristic dimension of the drag canopy is 100 ft., we may interpret the rules just stated to mean that

At heights where the air density relative to sea-level is between	The airflow may be dealt with by the methods of
1 and $1/10^3$	Gas Dynamics
$1/10^4$ and $1/10^7$	Slip Flow
$1/10^{10}$ and 0	Free Molecule Flow.

Nobody would pretend that these are hard and fast divisions, but at least they provide an indication of the importance of "superaerodynamic" phenomena. Slip flow differs from Gas Dynamics because the frictional forces and the heat transferred across the boundary layer are lessened by the slipping of the air at the surface. But frictional drag is only a small part of the drag of a body at very high speeds, so that the neglect of surface slip will have little effect on the accuracy of trajectory data. Also, as the deceleration of the missile at very high altitudes may be shown to be roughly equal to

$$\left(\frac{D}{W} \times 10^3 \times \text{relative air density}\right) \times g$$

it follows that the air resistance at heights where the air is no longer acting as a continuum is quite negligible.

Clearly by omitting to allow for the effects of slip flow in estimating the temperature reached by the missile's skin due to frictional heating, we shall be erring on the pessimistic side. But in free molecule flow, the heat transfer is large in forward facing regions where the surface slope is nearly perpendicular to the direction of motion. The underside of a drag-canopy is such a region, but I have calculated that in the descent to the altitude where the relative air density is $1/10^7$—where the air is to all intents and purposes acting as a continuum—the surface temperature will be only about 10° C. higher than the

air temperature. Again, superaerodynamic phenomena do not influence the issue to any important extent.

On the basis of conventional gas dynamic theory it is possible to show that the maximum skin temperature reached by the canopy is less than

$$20{,}000 \times \frac{W}{D} \times \frac{1}{\rho c t} \text{ °K}$$

where ρ is the specific gravity of the skin material, c its specific heat, and t its thickness in inches. Now, D = 2,600 lb./sq. ft. of frontal area, is a representative figure for the drag of a flat plate, so that it is possible to quote this temperature rise as equal to

$$\left(\frac{40}{c} \times \frac{\text{total missile weight}}{\text{canopy weight}}\right) \text{°K.}$$

Couched in this form, there seems no reason why the temperature rise should be prohibitively large. However, clearly the design of a suitable canopy presents an unusual structural problem and I would prefer to leave the matter in this interesting state for further discussion by those more qualified to discuss its construction.

It might appear, from the remarks we have already made about surface temperature and air pressure, that the design of a missile with a much lower drag—such that D/W is, say, about 10—would involve great difficulties. But, if the drag is provided by surfaces inclined at a small angle to the direction of motion—by a slender body and not a bluff one like the drag-canopy—this is not so. Working again with the assumption that the air is acting as a continuum, we may find the maximum skin temperature reached by a slender projectile during descent to be a function of the drag as shown in the Table below.

D/W \ $1/\rho ct$	45	30	15
5	2,050° C.	1,600° C.	1,100° C.
10	1,350° C.	1,100° C.	750° C.
20	1,050° C.	750° C.	500° C.

These maxima occur in the upper troposphere, and the figures can be fitted approximately to a formula:—

$$650\sqrt{\frac{W/D}{\rho c t}} = 40\sqrt{\frac{1}{kc}\left(\frac{\text{length}}{\text{radius}}\right)\left(\frac{\text{total missile weight}}{\text{skin weight}}\right)} \text{ °C.}$$

where k is the assumed drag coefficient on frontal area which must be small for the results to be accurate.

At first sight a material with a high specific heat would seem most appropriate, but in view of the large stresses set up in the skin of the missile occasioned by the high deceleration during descent, it is essential that a strong metal, such as steel, should be used, as a skin material. The permissible linear dimensions of the missile with a given type of construction vary as the

strength of the material used, which in turn varies with the maximum temperature reached. Thus, the larger the missile, the larger must be its cone angle (so that k is increased, the maximum temperature lowered, and the strength of the skin material improved). Above a certain size it will be necessary to use such a large cone angle that the design resembles that of the drag-canopy already discussed.

To quote an example: if the missile is constructed as an enclosed, pressurised cone with a 12° apex angle, formed of a single sheet of nimonic steel; then its maximum size would be limited to a diameter of 16 ft. This implies a skin thickness of 0·02 in., and a total weight of 2,000 lb. (including 200 lb. payload). The details of the descent of such a missile are given below.

Height above sea-level, ft.	Time secs.	Velocity ft./sec.	Retardation "g"	Excess air pressure on cone surface atm.	Skin Temp. °C.
150,000	0·0	36,700	12	0·04	5
125,000	0·7	35,900	30	0·14	93
100,000	1·4	34,200	110	0·46	344
90,000	1·7	33,000	170	0·72	450
80,000	2·0	30,900	248	1·02	570
70,000	2·3	27,800	323	1·33	682
60,000	2·7	23,300	380	1·52	785
50,000	3·2	17,300	356	1·34	868
40,000	4·0	10,100	241	0·74	904
35,000	4·6	6,060	146	0·30	900
30,000	5·9	2,140	42	0·04	849
27,000	8·0	750	0	0·00	742

The temperatures quoted here are the mean values over the skin thickness; the maximum value of this and the true surface temperature are roughly identical, since the net heat flux into the skin in this condition is zero. It is assumed that the inner surface of the skin is exposed to an insulating medium, and that the temperature is uniform over the entire surface.

Both these assumptions involve errors: conduction into the interior of the missile will lower the skin temperature; and it is likely that the nose of the missile will be hotter than other regions. But it must be confessed that the method of estimating heat transfer from the boundary layer is itself suspect. I have used the accepted methods of calculation relevant to the boundary layer at high Mach Number, correcting the results for the change in state of the air at high temperatures according to the deductions of Statistical Thermodynamics[2]; no account has been taken of the very rapid and *changing* rate of heat transfer or of the change in state of the air on the actual structure of the boundary layer. These are important omissions and future work on these problems is of more concern than discussions of molecular flow—which are at present more fashionable.

Nevertheless, the results of the calculations mentioned above will be seen to be encouraging enough to suggest that any refinements to the method of

calculation would not reveal them to be otherwise. Thus, whether the air resistance is provided by a canopy or a slender shroud, no difficulties are suggested which are beyond solution. The payload may be only a small part of the complete missile but this handicap is trivial compared with that incurred by carrying rockets to destroy the immense energy of the missile.

It is perhaps unnecessary to mention that the high deceleration involved in this form of descent makes it quite unsuitable for man-carrying missiles. They, however, have the advantage that aerodynamic controls may be operated by a pilot to effect a less precipitous return to Earth and avoid excessive deceleration. It is this problem of the winged-missile which we shall now examine.

From simple energy considerations it follows that the missile will make its first contact with the atmosphere when its speed is roughly equal to the escape velocity. It may readily be appreciated that at this speed a missile travels a very long way before coming to rest if its deceleration is limited to a small value. This implies that the angle of descent must be so small that the missile is, to all intents and purposes, in level flight. Moreover, it is essential that its orbit should be such that at some point of its path through the atmosphere it is travelling parallel to the Earth's surface. In other words, a tangential orbit is necessary and no *pull-out* into level flight is required.

For example, if the missile enters the atmosphere travelling straight towards the Earth's centre—assuming that the deceleration due to drag is small—then we may show that the maximum acceleration involved in a pull-out into level flight is at least $2{,}000\,g$! If the acceleration is limited to a value the human frame can stand, level flight is impossible as the missile would hit the ground before the pull out could be completed.

It is worth noting that even so small an angle of descent as 5° would involve difficulties in the pull out which might easily lead to the destruction of the missile or its crew. I am not qualified to say whether the likelihood of this happening is a real danger or not: clearly this depends on the accuracy of the astro-navigation.

Left to its own devices, a missile in a tangential orbit would perform several circuits of the Earth in decreasing ellipses as air resistance periodically retards its velocity, until it would be travelling in a circle round the Earth at only about 70 per cent. of the escape velocity. Subsequently it would spiral down to Earth. This change in the orbit from a parabola on the first entry to a near circle is termed a descent by "braking-ellipses."

I would first like to discuss whether it is possible to make a descent without employing any "braking-ellipses" in the process: if it is possible, then the prospects of a successful descent by more subtle means would indeed be bright. Assuming that level flight is required whilst the missile is travelling at the escape speed, the necessary acceleration perpendicular to the flight-path to be provided by the wings is given by the relation

$$\text{acceleration} = g - \frac{V^2}{r}$$

where g is the gravitational acceleration, r is the Earth's radius, and V is the missile speed which in the present example is equal to $\sqrt{2gr}$. Thus it follows

that the required acceleration is $-g$, the minus sign indicating that the force required must be directed towards the Earth to counteract the centrifugal force due to the high speed of rotation which is just twice the force of gravity.

For want of a better word we shall, nevertheless, term the force to be developed by the wings "lift" although plainly it is equal and opposite to the lift force normally required in aircraft flight. The change in orientation does not affect the problems involved.

The first difficulty is an obvious one: since the descent is gradual the skin is exposed to the air for such a length of time that the equilibrium state is effectively reached where radiation from the surface just equals the heat input from the boundary layer. Assuming homogeneous flow about a body inclined at a large angle to the direction of motion travelling at a speed equal to the escape-velocity, this equilibrium temperature rise is roughly given by

$$T = 20{,}000\,\sigma^{0.2}\ ^\circ K$$

where σ is the air density relative to that at sea-level. But at such a high speed the maximum lift coefficient* is only about 0·75 at an angle of attack of 55°, so that the highest altitude at which level flight is conveniently possible is implied by the identity:

$$\text{wing loading (lb./sq. ft.)} = 10^6\,\sigma.$$

Comparing these two relations we find the conditions at the height at which level flight is first possible to be given by the following data:—

Wing loading, lb./sq. ft.	0·1	0·3	1·0	3·0	10·0
Relative air density ..	10^{-7}	3×10^{-7}	10^{-6}	3×10^{-6}	10^{-5}
Height, miles	—	—	67	62	56
Skin Temperature without slip. °K.	800	990	1,260	1,570	2,000
Ditto, corrected for slip at surface	640	850	1,140	1,480	1,930

The effect of slipping of the air at the surface is evidently important at these low densities. It may be shown to reduce the heat conducted into the surface by a factor

$$1/\left(1 + a\frac{l}{\delta}\right)$$

where a depends on the accommodation coefficient, and has the approximate value 7/3 for air. Including this effect, assuming the wing chord to be 100 ft., the corrected values of the equilibrium temperature shown in the Table may be obtained.

Although the difference caused by this correction is appreciable, it is apparent that the skin temperature may be reduced to a reasonable value only

* Defined as (Lift/$\frac{1}{2}$ × air density × (velocity)^2 × wing area).

if the wing is designed to have an unreasonably low wing-loading. Whereas such a wing would not be required to provide a great deal of strength, it seems doubtful whether a wing-loading of less than 1 lb./sq. ft. could be achieved merely because the wing weight would itself be of this order—if the missile is to be any size. Yet even such a low wing-loading as this implies that the temperature rises to over 800° C.

It is necessary to examine if we have not inflicted this penalty upon ourselves by stipulating that level flight is assumed at a height where such high lift is necessary. But a more detailed examination of the relative effects of reducing heat transfer by decreasing the wing angle of attack and increasing the heat transfer by consequently having to fly in denser air suggests that right down to so low a lift coefficient as 0·02 the skin temperature increases. The change in the state of flow at still lower lift coefficients brings about a decrease in skin temperature, however, and corresponding to flight at a lift coefficient of 0·005 the temperature rise is given by

$$T = 3{,}000\,\sigma^{0.2}\ ^\circ\mathrm{K}.$$

The data of the following Table may then be calculated.

Wing loading, lb./sq. ft.	0·3	1·0	3·0	10·0	30·0
Relative air density ..	3×10^{-5}	10^{-4}	3×10^{-4}	10^{-3}	3×10^{-3}
Height, miles	51	45	37	30	25
Skin temperature, ° K. ..	420	530	660	840	1,040

These figures represent a temperature rise of only about a half of that which occurs if high lift coefficients are used, and consequently it would seem that the lower pull-out is the better proposition. However, the first assumption of level flight at a height much below 30 miles would involve not only high skin temperatures but also inconveniently large deceleration and severe torsional forces on the wing due to flutter. Thus a wing loading between 3 and 10 lb./sq. ft. would seem most appropriate.

For the rest of the voyage to Earth, little need be said. Provided that the "indicated air speed," $\sqrt{\sigma} \times$ true speed, is not allowed to increase above its value at the beginning of the glide the skin temperature will decrease during the descent, and no other complications should arise. Inside this speed limit there is the possibility of complete freedom of movement. The descent would take well over an hour to accomplish, during which time the missile could very nearly circle the Earth.

As we have already mentioned, because of the necessity of a tangential orbit, the difficulties associated with the requirement of level flight at the first contact with the atmosphere may be allayed by allowing the missile to perform a few braking ellipses (before the use of aerodynamic control). For instance, one may compute that a missile entering the atmosphere on a parabolic orbit tangential to the Earth at a height of 30 miles, will have its velocity reduced to

that appropriate to a circling orbit after describing four braking ellipses requiring only a few hours to perform, if its drag is such that the value of D/W—as originally defined—is unity. In other examples it is found that the number of braking ellipses required to attain a circular orbit varies roughly inversely to the density at the height of tangency and to the ratio D/W. If the orbit is tangential to the Earth at 60 miles height, about 400 circuits occupying several years would be necessary if the drag is given by $D/W = 1$, which is a figure typical of high-speed aircraft! The only methods of increasing the value of D/W, without impairing the flying qualities of the aircraft, is by thickening the wings or reducing the wing loading.

However, the few braking ellipses necessary at the lower altitudes represent no great handicap, and since the lift required to maintain level flight at a speed equal to that in a circling orbit is zero there is no need to provide a low wing-loading merely to keep down skin temperature; the wing loading would be fixed merely by the landing requirements. In fact, since the entry of the missile on each circuit into the atmosphere is only short-lived, the skin temperature does not reach a maximum until the missile is in the circling orbit where its velocity is only about 70 per cent. of the escape speed. This represents an advantage compared with the case of controlled flight at the first entry, as will be seen from the figures below:—

Height of circular orbit, miles	55	50	45	40	35	30	25
Maximum skin temperature, ° K.	320	390	460	530	600	710	860

Nevertheless, it is by no means evident that the low wing loadings mentioned in connection with the missile designed for direct descent represent a disadvantage. It is possible, though in my opinion unlikely, that such low loadings might be desirable from the structural point of view. This again is a question which need investigation; on its answer one may then judge whether the performance of braking ellipses is, or is not, an unnecessary practice.

Of course, there is no reason why braking ellipses should not be used to simplify the problems of the free descent without aerodynamic control. Provided the circuits are described at a sufficiently high altitude there is no reason why the problems of excessive skin temperatures should not thereby be allayed. The necessity of such a manœuvre is open to doubt, as I hope I have indicated in the first part of this discussion. Indeed, in retrospect I fear this discussion has been very inadequate. But I have attempted only to demonstrate that the descent into the atmosphere without "artificial" retardation holds no terrors, and I have chosen rather on the worst examples to strengthen my claim.

The problem of finding the easiest method of entry is, in my opinion, a far more difficult one—and which deserves much more detailed treatment than I could afford in this paper. It should, I think, be preceded by an adequate discussion of the heat transfer problems at high speeds of flight, which is the biggest and most important unknown quantity which affects the issues. How-

ever, if I have done enough to indicate that such labours would not be vain, I shall be satisfied.

In conclusion, I should like to thank Mr. Cross, a Fellow of the Society, for his help and advice in the preparation of this paper, and the Air Ministry for permission to publish the work.

REFERENCES

(1) Hsue-Shen Tsien, "Superaerodynamics, Mechanics of Rarified Gases," *Jour. Aero. Sci.*, Dec., 1946.

(2) Fowler and Guggenheim, *Statistical Thermodynamics*. (C.U.P.)

NOTES AND NEWS

Film Shows—London, Manchester, and Birmingham

We are very pleased to announce that it has been possible to arrange a programme of rocket films which will be shown in London, Manchester, and Birmingham, as below:—

(*a*) March 17, 1951, at the Central Technical College, Suffolk Street, Birmingham, 6 p.m.

(*b*) March 24, 1951, at the Science Museum Lecture Theatre, Exhibition Road, London, S.W.7, 10.30 a.m. and 6 p.m.

(*c*) March 31, 1951, at Adult Education Institute, 49, Lower Mosley Street, Manchester, 2 (near Central Station), 2.15 p.m.

Unfortunately, it is not possible at this stage to give the exact titles of the films to be screened, but several are of recent American origin which have only just been made available.

Admission to all programmes is *by ticket only*. Tickets for the Manchester show should be obtained from the Branch Secretary, E. Burgess, 4, Cordova Avenue, Denton, nr. Manchester, Lancs., while tickets for the shows in London and Birmingham should be obtained from the B.I.S. Secretary, at 157, Friary Road, London, S.E.15. All applications should be accompanied by a *stamped addressed envelope* for reply.

Intending visitors to the London screening should note that the programme will be shown at 10.30 a.m. and again at 6 p.m., by courtesy of the Director. The evening show is intended primarily for members, and the morning show for non-members, but the distinction is not rigid, and members should specify which screening they wish to attend.

Fifth Annual General Meeting

A very lively discussion took place at the Fifth Annual General Meeting which was held at the Kent Room of Caxton Hall on Friday, December 8, 1950.

The Chairman opened the proceedings by drawing attention to the main points contained in his printed address, which had been circulated to all members with the Annual Report, amplifying this where necessary in answer to several subsequent questions, and then formally proposed the adoption of the annual accounts. This was seconded by Mr. E. Hope-Jones and carried unanimously.

A small item of legal business was then transacted, the proposal for the

authorised number of the Society's members to be indefinite being proposed again by the Chairman and seconded by Mr. A. E. Dixon.

The report of the Scrutineers was then announced, as follows:—

(*a*) Number of ballot papers received 309 (as against 227 last year).

(*b*) Number of papers declared invalid, 1.

(*c*) Names of the candidates elected:—

E. Burgess	Dr. A. E. Slater
A. C. Clarke	R. A. Smith.

The Chairman extended his congratulations to those who had been successful, and asked the meeting to extend a vote of thanks to Messrs. A. M. Kunesch, P. A. Moore, and M. W. Wholey, the candidates who had not been successful, for their interest and enthusiasm in allowing themselves to be nominated. He hoped that there would always be a number of members who would be willing to come forward in this way, for it reflected favourably on the interest of members and the vitality of the Society.

After the formal business had been transacted, a large number of questions were asked on different aspects of the Society, to which the Chairman and Secretary replied as necessary. A number of points raised could not be adopted at the present time owing to considerations of finance, but many were worthy of later attention as soon as the Society was in a position to afford them. A member raised the question of whether repeat film shows could be held for the benefit of members unable to attend earlier showings. The Secretary replied to this that we did intend to do so, but it was not possible to hold more frequent shows owing to the fact that we did not wish to embarrass the Authorities of the Science Museum, and alternative accommodation had proved exceedingly expensive. Certain other points were noted to be dealt with by the Council in due course.

At the first meeting of the new Council following the Annual General Meeting, Mr. A. C. Clarke was elected Chairman for the session 1950/1.

London Lectures—an Apology

Both the November and December, 1950, meetings were characterised by a heavy attendance on the part of members, and it is very greatly regretted that a number of those who wished to attend had to be turned away, in spite of every endeavour on the part of the B.I.S. officials present to accommodate them.

The influx was unexpected since the October meeting had opened with ample accommodation relative to the number of members present, and as it is not possible to change bookings of halls at short notice (the Society's bookings are normally one year ahead), members will appreciate the difficulties which may suddenly confront us.

While every endeavour will be made to accommodate members during the present session, we must ask for their indulgence in some cases. We shall watch the position closely to determine if the general level of attendances continues to increase, and will endeavour to provide greater accommodation next session if found to be necessary.

Meanwhile, we suggest that members who have a particular interest in some lecture should endeavour to arrive early, and this is particularly desirable in the case of some members who have travelled long distances and whose disappointment is particularly great.

New Technical Publications

We have just received from Messrs. Butterworth-Springer copies of two important new publications which are likely to be of interest to members.

(*a*) *The Journal of Atmospheric and Terrestrial Physics*, Editor-in-Chief Sir Edward Appleton, will cover the whole field of geophysics, ionospheric physics, cosmic rays, radio physics and associated subjects. The first issue contains a paper giving the results of chemical analyses of stratosphere samples obtained by V.2 from 50 to 75 kilometres height.

(*b*) *Geochimica et Cosmochimica Acta* will be concerned with the chemical composition of the Earth and cosmos, and the first issue contains a number of papers on meteor analyses.

The subscription rate to both journals will be £3 10s. per volume of approximately 300 pages. The *Journal of Atmospheric and Terrestrial Physics* will appear about every two months: *Geochimica et Cosmochimica Acta* at irregular intervals. Papers will be in English, French and German, with English abstracts.

Subscriptions should be sent to Butterworth-Springer, Ltd., Bell Yard, Temple Bar, London, W.C.2.

Second International Congress on Astronautics

The dates for the above Congress, to be held at Caxton Hall, London, have now been fixed as follows:—

(*a*) 3rd and 4th September, 1951: private sessions to deal with procedural matters affecting the various national societies, and to inaugurate formally the International Federation of Astronautical Societies which was agreed upon at the 1950 Paris Congress.

(*b*) 6th, 7th and 8th September, 1951: public sessions, at which technical lectures on astronautics will be delivered by representatives from the various national societies.

Further details will appear in this *Journal* in due course.

"The Flying Saucer Mystery"

A short film with the above title has recently been on show in London news-reel theatres, and though it cannot be said to contribute much to the study of these annoying phenomena, it is not without interest. The U.S. Air Force apparently refused to co-operate, for we see only a representative of the Navy, who states flatly (*a*) that flying saucers happen and (*b*) that they are nothing to do with him. Of course this might only prove that they were Air

Force projects classified as TOP SECRET (i.e. not to be revealed to the Navy) and not merely SLIGHTLY SECRET (not to be revealed to the Russians).

Highly unconvincing is an interview with a young man who describes a saucer sighting in such minute detail (giving velocities and times with a precision that suggests he would make a good stand-in for a kine-theodolite) that it practically removes his story from the bounds of credulity. In fairness, however, it should be remarked that some genuine witnesses *do* tend to do this sort of thing when they have repeated their stories too often.

Even less impressive is what purports to be a film of a flying saucer. All that is visible is a small black disc pulsating slowly against a cloudy sky. This sequence looks so obviously faked that, on the principle that a better job would have been made of it if it *was* a fake, one is almost tempted to accept it as genuine!

Two stills of a flying saucer, bearing an uncanny resemblance to an airborne dustbin lid, are also shown, and a picture agency chief certifies that the negatives show no signs of having been tampered with. Nor, of course, need they have been, since there are several ways in which such photographs could be obtained without touching the negative.

Donald Keyhoe, author of *The Flying Saucers are Real* (see this *Journal*, Nov., 1950, p. 299), also appears and restates his case.

The film contains a number of rocket sequences, including the launch of the V.2-WAC Corporal rocket and the NATIV. It ends with the famous view of the Earth from space, a model of a Keyhoe-designed flying saucer pirouetting among the stars, and—how did you guess?—a big question mark.

Journal Binding Cases—Increase in Price

We are advised by the makers of our self-binding Journal cases that they have been compelled to increase their charges owing to the continued advance in costs of labour and materials.

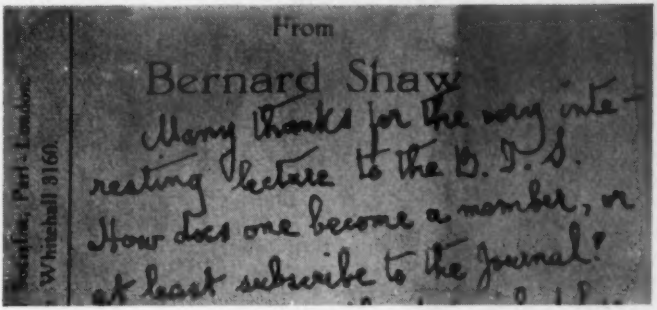
By making an original large order in bulk, the Society has hitherto been able to supply these cases at 5s. 6d. each, post free, but the lowest price at which they may now be offered to members is 6s. 6d., post free, and this will apply with immediate effect, as our original stock has been exhausted.

The binders were originally supplied in response to a number of requests from members, and have always been sold at cost price.

Groupement Astronautique Français

We are pleased to announce that M. Alexandre Ananoff was, during the month of November last, elected President of the French Aero Club. The *Groupement Astronautique Français*, founded by M. Ananoff and directed by him ever since its inception, is, of course, a subsidiary of the Aero Club. M. Laming has been appointed Secretary of the G.A.F., also with effect from November.

Incidentally, we take this opportunity of recording that *l'Astronef* (the organ of the G.A.F.) now runs to 32 pages per issue—another sign of the growing periodical literature of astronautics.


From
Bernard Shaw
Many thanks for the very interesting lecture to the B. I. S.
How does one become a member, or at least subscribe to the Journal?
Whitehall 3160.

G. B. S.
(Member: 1947–1950.)

From the World's Press

On September 11 *The Scotsman* (Edinburgh) carried a report that the Russian Air Force was now testing a new supersonic rocket-propelled interceptor fighter. Developed by the Russian designer Alexander Yakovlev from the German war-time Me. 163b, the aircraft is stated to bear the type designation Yak 21. The main difference from the earlier Messerschmitt-Lippisch design was said to be the incorporation of a horizontal tailplane, to improve longitudinal stability in the region of trans-sonic speeds.

* * * *

Many papers recently commented on a spaceship model exhibited at the annual show of the Brighton and Hove Society of Model Engineers during September. Made by Messrs. G. H. Davis (the well-known technical artist), G. Clasby and W. H. Walter, the model was 6 ft. high and intended to represent a 150 ft., 300 ton, original; the builders said this should be possible to construct in ten years or so from now, and that their design embodied all the latest information from the American and British interplanetary societies. At the time of writing, we have not personally seen this model; we welcome its appearance, however, and hope the preceding statement is true: in view of Mr. Davis's association with the project, there seems a good chance that it is, because *The Illustrated London News* (to which he is such a frequent contributor) often publishes items about rocketry and astronautics.

* * * *

Dr. J. Kaplan, Professor of Physics at the University of California, told the Press that he thought future spaceships might solve their propellant problem by replenishing their fuel stocks from the "chemosphere", an atmospheric layer 26 to 70 miles up which is rich in the hydroxyl molecule (OH). An interesting idea, but we doubt if it would bear very close examination when the ambient density of the gas was taken into consideration.

Additions to Lending Library

The following books have now been added to the Society's Lending Library and are available to Fellows holding Library tickets:—

Die Entwicklung des Raketenantriches in allgemein Verständlicher Darstellung (3 vols), by J. Stemmer (1944–5).
Tuyères, Trompes, Fusées et Projectiles Problèmes divers, de Dynamique des Fluides aux Grand Vi¹esses, by M. Roy (1947).
Analysis of Temperature, Pressure and Density of the Atmosphere Extending to Extreme Altitudes, by G. Grimminger (1948).
La Planète Mercure et la Rotation des Satellites, by E. M. Antoniadi (1934).
Worlds without End, by Sir Harold Spencer Jones (1935).
Saturn and its System, by R. A. Proctor (1882).
Rocket Research, by C. P. Lent (1945). *Presented by Mr. G. R. G. Chart.*
The Moon, by Nasmyth and Carpenter (1903).
The Structure of the Universe, by G. J. Whitrow (1950).
Physics of the Sun and Stars, by W. H. McCrea (1950).
The Universe Around Us, by Sir James Jeans (1929).
Through Space and Time, by Sir James Jeans (1934).
A La Conquista Del Espacio, by J. J. Maluquer (1946).
The Boys Book of Rockets, by R. F. Yates (1950).

Erratum

We regret an error on p. 192 of the July *Journal*, where the date of discovery of Nereid, the new satellite of Neptune, is given as May 1, 1950. This should, of course, read May 1, 1949.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950, issue of the *Journal* and addenda appeared in the July, September and November issues. The following is a further addendum to the list.

Heat Transf. Fluid Mech. Inst.	Heat Transfer and Fluids Mechanics Institute.
J. Inst. Navig.	Journal of the Institute of Navigation.
Z. Naturforsch.	Zeitschrift für Naturforschung.

Many of the Abstracts noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

AERODYNAMICS

(1) **A rocket researcher's reflections on supersonic flight.** H. OBERTH. *Interavia*, **5**, 382-5 (1950).

(2) **Molecular aerodynamics.** M. LUNC. *Technika Lotnicza*, **5**, 39-52 (*Sept.*, 1950). (*In Polish.*)

(3) **Lift on inclined bodies of revolution in hypersonic flow.** G. GRIMMINGER, E. P. WILLIAMS and G. B. W. YOUNG. *J. Aero. Sci.*, **17**, 675-90 (*Nov.*, 1950). (21 refs.)

AIRCRAFT

(4) **My flight experience with the Me 163.** R. OPITZ. *Flugwelt*, **2** (7) (*July*, 1950). (*In German.*)

ASTRONAUTICS

(5) **The way to the stars.** V. Borissov. *Znanie-Sila* (4) (1950). (*In Russian*).
A history of the evolution of astronautics in Russia.

(6) **Space-flight and its problems.** E. Dicke. *Flugwelt*, **2** (5) (*May*, 1950). (*In German.*)

(7) **The space-ship cabin.** A. Ananoff. *Astronef* (1), 12-20 (*Sept.*, 1950). (*In French*).
A detailed discussion of the requirements of a cabin, extracted from *L'Astronautique*.

(8) **How astronautics will evolve.** A.-L. Hirsch. *Astronef* (1), 21-3 (*Sept.*, 1950.) (*In French.*)
Shows how astronautics has passed from small private groups to Government research establishments.

(9) **Concerning some limits of astronautics.** E. Sänger. *Astronef* (1), 8-10 (*Sept.*, 1950.) (*In French.*)
A discussion of some of the relativity effects on space-ships travelling near the speed of light.

(10) **Present limitations of rocket propulsion and the prospect for space-flight.** R. H. Reichel. *Z. Ver. dtsch. Ing.* [*V.D.I.*], **92**, 873-82 (11*th Nov.*, 1950). (*In German.*)
A study of step-rockets and methods of propulsion. It is shown that chemical rockets are useless for space-flight. An analysis of nuclear energy applied to heat a reaction mass and used directly as radiation shows that this, too, would be insufficient for a return trip to the Moon—assuming that the same amount of energy would be required in each direction. It is concluded that space-flight is impossible unless a completely new approach to the problem is discovered.

(11) **Some problems of interplanetary navigation.** R. d'E. Atkinson. *J. Inst. Navig.*, **3**, 365-73 (*Oct.*, 1950).
Methods of determining the position of a space-ship in space.

(12) **The dynamics of space-flight.** A. C. Clarke. *J. Inst. Navig.*, **3**, 357-64 (*Oct.*, 1950).
Discussion of types of path which would be followed on any interplanetary journey either by unmanned guided missiles or true space-ships.

(13) **What is thought of interplanetary flight?** R. Richard-Foy. *Études*. **267**, 55-66 (*Oct.*, 1950). (*In French.*)

(14) **Flight path determination in space. Pt. 2.** W. Schaub. *Weltraumfahrt* (5), 106-8 (*Oct.*, 1950). (*In German.*)
The apparent path of a space-ship to a fixed observer on Earth and means of determining the true path.

BIOLOGY AND MEDICINE

(15) **The problem of health hazards from cosmic radiation in flight at extreme altitudes and in free space.** H. J. Schaefer. *Contact*, **7**, 14-20 (*July*, 1949).

CHEMISTRY

(16) **Equilibrium of solution of the nitromethane-water system ($CH_3.NO_2/H_2O$).** R. M. Corelli. *Aerotecnica*, **30**, 32-7 (15*th Feb.*, 1950). (*In Italian.*)

MATERIALS

(17) **What's ahead in metals.** *Prod. Engng.*, **21**, 87-102 (*Oct.*, 1950).
A summary of recent noteworthy advances in the metals and metal fabrication fields.

MISCELLANEOUS

(18) **The Peenemünde rocket centre, Pt. 3.** K. A. Ehricke. *Rocketscience*, **4**, 57-63 (*Sept.*, 1950).
Brief description of the 1,000 kg. assisted take-off unit, using liquid oxygen and 75 per cent. alcohol. This was first tested in 1940 and was in operation in 1942. The A.4 is described in some detail with performance figures and information on the propulsion unit, control systems and methods of radio tracking.

(19) **With rocket post into space.** R. Köhler. *Ad Astra* (9), 93-4 (*Oct.*, 1950.) (*In German.*) Historical survey of rocket posts.

(20) **The inauguration of the rocket station, Florida.** W. Ley. *Weltraumfahrt* (5), 115-7 (*Oct.*, 1950). (*In German.*) Firings of Bumper WAC.

PHYSICS

(21) **Measurements of the Earth's magnetic field at high altitudes at White Sands, New Mexico.** S. F. SINGER, E. MAPLE and W. A. BOWEN. *Phys. Rev.*, **77**, 398-9 (*1st Feb.*, 1950).

(22) **Cooling by forcing a fluid through a porous plate in contact with a hot gas stream.** M. JAKOB and I. B. FIELDHOUSE. *Heat Transf. Fluid Mech. Inst.*, 191-200 (*May*, 1949). [Abs. in *Appl. Mechs. Revs.*, **3**, 250 (*Aug.*, 1950).]

(23) **The emission of radiation from nitric oxide: approximate calculations.** L. E. BENITEZ and S. S. PENNER. *J. Appl. Phys.*, **21**, 907-8 (*Sept.*, 1950).
Emissivity calculations have been carried out for nitric oxide at temperatures from 300° K. to 3,000° K. The results may be used, as a first approximation, at elevated total pressures.

(24) **Study of the use of a cooled probe for sampling hot combustion gas as a means for determining heat release.** P. E. ERBE, J. T. GREY and J. L. BEAL. *Squid Technical Memorandum No. Cal.-8, Cornell Aeronautical Laboratory, Inc.*, 14 pp. (*1st Sept.* 1948). Presents experimental work on sampling gases at up to 4,200° F.

PHOTOGRAPHY

(25) **A low-cost, 16 mm. camera for rocket photography.** R. E. MUESER and T. F. IRVINE. *J. Amer. Rocket Soc.* (82), 119-25 (*Sept.*, 1950).
Modifications to a military surplus camera to make it suitable for trajectory determination.

PROJECTILES

(26) **The modern large rocket and its history, Pts. 2 and 3.** N. LITTERST. *Ad Astra* (8 and 9) 70-3, 101-2 (*Aug. and Oct.*, 1950). (*In German.*)
Descriptions of the A.4 and other German war rockets.

(27) **Rockets for studying the upper atmosphere.** J. A. VAN ALLEN. *Aero Dig.*, **61**, 20-1, 88-91 (*Sept.*, 1950).
A survey of existing high-altitude rockets, their performance characteristics, problems involved in their firing, recovery techniques and the types of research for which they are used.

(28) **Weapons of the future. I. The rocket.** *Defense*, 20-1, 30 (*Oct.*, 1950).
Brief discourse on aircraft rockets.

(29) **Brake aids free-fall salvage.** *Aviation Wk.*, **53**, 25 (*2nd Oct.*, 1950).
Umbrella-type brake, giving constant drag for recovery of free-falling bodies.

RADIO AND ELECTRONICS

(30) **DOVAP—a method for surveying high-altitude trajectories.** D. HOFFLEIT. *Sci. Mon.*, **68**, 172 (1949). [Condensed version in *Weltraumfahrt* (5), 117-20 (*Oct.*, 1950). (*In German.*)]
A signal is sent from a ground station to the projectile where it is received, the frequency doubled and re-transmitted. Three ground-stations receive this signal and by means of the Doppler effect and by triangulation the path and velocity along the path of the projectile can be determined.

ROCKET MOTORS

(31) **The HWK 109-509 rocket motor of Walter-Werke, Kiel.** *Flugwelt*, **2** (6) (*June*, 1950). (*In German.*)

(32) **De Havilland Sprite assisted take-off rocket.** THE DE HAVILLAND ENGINE COMPANY, LTD. 19 pp. (*July*, 1950).
General description of the unit followed by the technical specification and installation notes. The special refuelling trolley and operational procedure are also dealt with.

(33) **Stability of flow in a rocket motor.** D. F. GUNDER and D. R. FRIANT. *J. Appl. Mech.*, **17**, 327-33 (*Sept.*, 1950).
This paper presents an analytical treatment leading to a criterion for the proper design of liquid rocket motors to ensure freedom from the phenomenon of "chugging" without unnecessary increase in fuel-tank or fuel-pump pressures. The most successful of the several methods suggested here is that of Nyquist which involves a simple conformal transformation. The analytical treatment presented has been applied successfully in practice to eliminate this type of instability.

(34) **Problems facing the rocket industry relating to military planning.** H. B. HORNE. *J. Amer. Rocket Soc.* (82), 107-118, 125 (*Sept.*, 1950).

The paper is limited to liquid-propellant motors. In the development of motors it is likely that there will be more standardisation; standard-thrust motors will be produced and propellants, in time, will also be standardised. The value of field experience is emphasised and it is recommended that trial batches of motors should be produced even if not required, just to make sure that production experience is available.

(35) **The optimum velocity, Pt. I.** H. OBERTH. *Rocketscience*, **4**, 51-6 (*Sept.*, 1950).

Translation from *Wege zur Raumschiffahrt*. Deals with the optimum velocity for a rocket ascending from the Earth's surface.

(36) **The turborocket-propellant feed system.** A. G. THATCHER. *J. Amer. Rocket Soc.* (82), 126-38 (*Sept.*, 1950).

The first part of the paper presents general turbo-pump systems and flow diagrams. Possible turbopump cycles are discussed. The second part deals with factors involved in tubo-pump design; centrifugal pumps and impulse turbines are dealt with. The last part discusses operational problems.

(37) **Microrocket.** *Mech. Engng., N.Y.*, **72**, 816-7 (*Oct.*, 1950).

This rocket motor uses only 2 lb. of propellant per minute and has been designed for testing new and scarce fuels, thus reducing costs of tests or for solving special problems, such as the effect of temperature on ignition.

(38) **Cooling of the rocket combustion chamber.** H. GARTMANN. *Weltraumfahrt* (5), 109-14 (*Oct.*, 1950). (*In German.*)

Three methods of cooling are considered:—capacity, regenerative and film. Using the heat capacity of the material of construction has limited applications; it can be used with solid fuels for burning times up to 50 secs and with liquids for up to 25 secs. Regenerative is the most commonly used and it is stated that it is better to use a thin axially-flowing cooling layer than to use swirls. Details of the film-cooled 109-718 combustion chamber are given. Forty-five per cent. of the fuel was injected as a film at the head of the chamber and 90 per cent. of this coolant was burnt. An exhaust velocity of 2,200 m./sec. was attained.

(39) **Britain unveils rocket motor.** *Aviation Wk.*, **53**, 30 (*9th Oct.*, 1950).

Description of Beta motor which uses hydrogen peroxide and an unnamed fuel. Propellants are fed by a turbo-pump into the two combustion chambers.

ROCKET PROPELLANTS

(40) **Liquid oxygen as an oxidant for rocket propulsion.** R. C. MURRAY and J. M. F. WHITE. *A.R.C. Reports and Memoranda, No.* 2367, 14 pp. (1950.)

An evaluation of liquid oxygen as an oxidant for rocket propulsion, in competition with other oxidants, is presented. Methods of production, storage, transport, transfer and use in rockets are reviewed and discussed, and the risks in handling outlined. Comparative performance calculations for the propellants, liquid oxygen/kerosene, nitric acid/kerosene and hydrogen peroxide/kerosene are given. It is concluded that since the volume of plant required for liquid oxygen-based propellants is very high compared with that for nitric acid or hydrogen peroxide, it can only be considered for units on aircraft where this is a secondary consideration, and low price and accessibility are of greater importance.

(41) **Anomalous rates of burning in cordite.** J. D. HUFFINGTON. *Nature*, **165**, 840-1 (*27th May*, 1950).

(42) **Hypothesis on powder burning.** E. SÄNGER. *Z. Naturforsch.*, **5a**, 467-8 (*Aug.*, 1950). (*In German.*)

Heat required to bring powder up to the reaction temperature is supplied by chemiluminescence. Calculations on this basis of the velocity of burning of ballistite at different ambient temperatures agree with practice.

(43) **Introduction to rocket technique. Pts. 4 and 5.** H. OBERTH. *Ad Astra* (8 and 9), 75-80, 95-100 (*Aug. and Oct.*, 1950). (*In German.*)

Pt. 4 is a discussion on propellants, both solid and liquid, which is continued in Pt. 5, together with simple adiabatic expansion laws.

(44) **The flame photography of gunpowder.** A. J. ZAEHRINGER. *Rocketscience*, **4**, 65-6 (*Sept.*, 1950).

(45) **Application of white fuming nitric acid and jet-engine fuel (AN-F-58) as rocket propellants.** M. J. ZUCROW and C. F. WARNER. *J. Amer. Rocket Soc.* (82), 139-50 (*Sept.*, 1950).

Performance curves for WFNA/octane over a range of chamber pressures, mixture ratios and exist pressures are given. This propellant combination gives the same performance as WFNA/AN-F-58 and the results are used throughout. Experimental work on ignition by means of a hot plate are given. Cooling is extensively treated and curves of the physical properties of the combustion gases are given. It is concluded that regenerative cooling should be possible for combustion chamber pressures up to 1,200 lb./in., but above that pressure some form of film cooling would be needed. (12 refs.)

REVIEWS

The Structure of the Universe

(By G. J. Whitrow, M.A., D.Phil., F.R.A.S. Hutchinson's University Library, No. 29. Pp. 171. London: Hutchinson's Scientific and Technical Publications, 1949. 7s. 6d. net.)

The University Library aims at providing "popular, yet scholarly introductions for the benefit of the general reader, but more especially for the unprofessional student who wishes to pursue his chosen subject systematically up to something like a University standard." Dr. Whitrow's book is an admirable and very suitable addition to the series.

For the benefit of the general reader, mathematics are avoided assiduously, but perhaps too assiduously for the student. Cosmology is not, perhaps, the easiest of subjects to treat in a popular manner while at the same time giving the bones of the arguments and developments (although all too easy to deal with from an uncritical and entirely descriptive point of view). The author develops the interdependent themes of observation of the metagalaxy, the difficulty of interpreting directly the observational data, and the philosophical approach which plays such a prominent role in cosmological theory. The author preserves a healthy critical faculty throughout, with the possible exception to the treatment of Milne's Kinematical Relativity, in the development of which the author has made significant contributions.

Dr. Whitrow has tackled a difficult task with assurance, and his book can be confidently recommended as an authoritative introduction to the widest field of modern scientific speculation. M. W. O.

Physics of the Sun and Stars

(By W. H. McCrea, M.A., Ph.D. Hutchinson's University Library. Pp. 192, with 8 figs. London: Hutchinson's Scientific and Technical Publications, 1950. 7s. 6d. net.)

In this companion volume to *The Structure of the Universe*, Prof. McCrae treats the subject of the internal constitution of the stars in a similar manner. He finds it impossible completely to avoid mathematical expressions, but the methods used are of the simplest. It is indeed illuminating to see how much of the present complex studies of internal constitution the author is able to develop by the use of relatively simple physical arguments (although he does not lead the reader to suppose that the original development could have been made entirely without mathematics). He has to spend nearly half of the text on a survey of the relevant branches of modern physics (atomic theory, spectroscopy, etc.), before describing the observational details of the sun and stars,

from which the reader is taken, step by step, to an understanding of the stellar interior. At all stages, the author is careful to emphasise the incompleteness of our present knowledge.

The general reader will find in Prof. McCrae's book an invaluable development of the subject well suited to his needs, and one which will prove of value to many a student who would not care to be styled a "general reader."

M. W. O.

The Computation of Orbits

(By Paul Herget. Published privately by the author, Cincinnati Observatory, Cincinnati 8, Ohio, 1948. Pp. ix + 177. $6.25.)

This book is a remarkable tribute to the author's devotion and industry, since the whole of the typographical material was prepared by his own hands on an I.B.M. Electromatic Proportional Spacing typewriter in order that the work might be issued at a reasonable price. The result is practically indistinguishable from printing and can stand comparison with any well-produced mathematical book.

The Computation of Orbits is not for the beginner, but serves as a concentrated reference book for the serious student. The first three chapters are introductory and deal with the calculus of finite differences, spherical astronomy and the problem of two bodies. Vector methods are used throughout the book. The methods of Laplace and of Gauss and Olbers are then discussed, and chapters are devoted to the improvement of the orbit, special perturbations and Hansen's method of general perturbations. The book ends with a set of tables particularly designed for use with calculating machines.

Every chapter opens with a quotation whose aptness is hidden from all but classical scholars. In view of Ben Jonson's famous remark on the subject, one would like to know what justification there is for quoting Shakespeare, of all people, in Greek!

A. C. C.

CORRESPONDENCE

Meteors and Space-travel

SIR,

I have a great respect for the perspicacity of our distinguished Honorary Fellows, but since I am possessed by a profound philosophical faith in the ultimate possibility of interstellar travel, I feel bound to question von Pirquet's statement, in the July *Journal*, that "because of cosmic dust the interstellar rocket is completely impracticable."

I do not question the validity of von Pirquet's methods of calculation (based on Grimminger), but would point out that the basic data—the meteor 'content of space'—relates to our knowledge of conditions close to the Earth. Are we right in assuming that the meteor content of interstellar space is of the same high order?—and, if so, at what distance would space become opaque?

Secondly, I am not convinced that interstellar rockets cannot be effectively armoured against the "cosmic dust," even if some of the dust particles are asteroids. For one thing, would it not be possible to provide our accelerated interstellar rocket with an atmospheric meteor bumper? One comparable in

extent with that which envelopes the Earth. Again, are we sure that our interstellar rockets will be machines? Might they not be worlds? Should we not bear in mind Zwicky's opinion that:—

"In the wake of the realisation of large-scale nuclear fusion there will, no doubt, follow plans for making the planetary bodies habitable by changing them intrinsically and by changing their positions relative to the Sun."

Inside a world one could laugh at meteors, even if for a very long time one did not have much else to laugh about.

H. E. Ross.

High Wycombe, Bucks.

SIR,

Russian Rocket Pioneers

While I am very grateful to Mr. Bialoborski for having called my attention to my mistake about the year of Kibaltchitch's sudden demise, I feel that Mr. Bialoborski has caused some unnecessary confusion by his indiscriminate use of the Polish forms of Russian names, including that of the political party of which Kibaltchitch was a member. Its name was *Narodnaya Volya*, not *Narodna Wola*.

Of course there are several ways of transliterating from the Russian alphabet but the logical thing, to my mind, is to transliterate in such a way that the reader will pronounce the names in a manner that is reasonably close to the original sound. Hence one has to use different transliterations for different audiences, depending on the native tongue of the audience. I doubt whether any English-speaking reader will be able to do anything with such accumulations of letters as "Kibalczyc" and "Hryniewiecki." Straight transliteration from the Cyrillic alphabet produces Kibaltchitch and Grinevitski.

Since *Rockets and Space Travel* is not a history of a political movement I naturally did not go into the details of the assassination of Alexander II. But since Mr. Bialoborski's mention of the execution of Countess Perovskaya may lead some of the readers of my book to think that my statement about "death sentences for all except one of the defendants who was a woman" is wrong, I have to add a few words here. There was a total of six defendants on trial, Grinevitski had died as a result of the explosion of the second bomb. Of these six defendants two were women, Countess Sophia Lvovna Perovskaya and Gesya Mironovna Gelfman (or Helfman). It was the latter whose death sentence was commuted to imprisonment for life because she reported herself pregnant. (She died one year later, in 1882.) Countess Perovskaya, in spite of her rank, was executed by hanging along with the four male defendants of whom Kibaltchitch was the first to die.

The information that Ziolkovsky's father was a Pole is interesting; still Ziolkovsky has to be considered a Russian since he was born in Russia, published exclusively in Russian and lived in Russia all his life. I was never informed about the date of his death, I only learned that he died four years after the celebration of his 75th birthday. Arithmetically that worked out to be 1936, but the year 1935 is equally probable.

WILLY LEY.

Jackson Heights, N.Y., U.S.A.

RECENT AND FORTHCOMING MEETINGS

October 18, 1950 (Wednesday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Coventry Branch of the Royal Aeronautical Society.

November 6, 1950 (Thursday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Empire Test Pilots' School, Farnborough, Hants.

November 14, 1950 (Tuesday). "Into Space," by E. Burgess, to Manchester University Physical Society, the Physical Laboratories, Manchester, 16, at 4 p.m.

November 18, 1950 (Saturday). "Interplanetary Flight," by E. Burgess, to Derbyshire and Lancashire Gliding Club, Camphill, Gt. Hucklow, Derbyshire.

November 23, 1950 (Thursday). "Rockets and Assisted Take-off," by A. V. Cleaver, to the Royal Aeronautical Society, at the Institution of Civil Engineers, 6 p.m.

November 25, 1950 (Saturday). "The Galaxy," by J. C. Farrer, to the N.W. Branch of the Society, at the Adult Education Institute, 49, Lower Mosley Street, Manchester, 2, at 7 p.m.

November 28, 1950 (Tuesday). "Into Space," by E. Burgess, to the Chorlton Men's Fellowship, at Chorlton-cum-Hardy, Manchester, at 7.30 p.m.

November 28th, 1950 (Tuesday). "Interplanetary Travel and Astronomy," by G. V. E. Thompson, to the Astronomical Society, Bedford College, Regent's Park, London, N.W.1, at 5.15 p.m.

December 3, 1950 (Sunday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Wealdstone and Harrow Branch of the Y.M.C.A.

December 6, 1950 (Tuesday). "Rockets and Interplanetary Flight," by J. Humphries, to the Society of Licensed Aircraft Engineers (Blackbushe Branch,) Blackbushe Airport, nr. Camberley, Surrey, 6.30 p.m.

December 13, 1950 (Wednesday). "The First Moon Rocket," by E. Burgess, to the Holiday Fellowship, at the Geographical Hall, Parsonage, Manchester, at 7.30 p.m.

December 15, 1950 (Friday). By ticket only, N.W. Branch visit to an astronomical observatory, at 8 p.m.

December 13, 1950 (Wednesday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Preston Branch of the Royal Aeronautical Society.

January 1, 1951 (Monday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to St. Albans, A.T.C.

January 3, 1951 (Wednesday). "Interplanetary Travel," by E. Burgess, to Metropolitan-Vickers Apprentice Association, Moss Road, Stretford, at 7.15 p.m.

January 6, 1951 (Saturday). "A Symposium on the Orbital Rocket," by K. W. Gatland, A. E. Dixon, and A. M. Kunesch, to the Society at Caxton Hall, at 6 p.m.

January 20th (Saturday). "The Challenge of the Spaceship," by A. C. Clarke, to the N.W. Branch of the Society, at the Adult Education Institute, 49, Lower Mosley Street, Manchester, 2, at 7 p.m.

January 27, 1951. "Liquid-Propellant Rocket Motors," by J. Humphries, to the Society of Licensed Aircraft Engineers, South-East Area. Manston House, Portland Place, W.1, at 3 p.m.

January 30, 1951 (Tuesday). "Space Flight," by L. J. Carter, to the Norwood Branch of the International Friendship League, St. Luke's Church, West Norwood, at 8 p.m.

January 30, 1951 (Tuesday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to King's School, Canterbury, Kent.

February 2, 1951 (Friday). "Interplanetary Flight," by E. Burgess, to the Loughborough College Scientific Society, Leics., at 7.15 p.m.

February 3, 1951 (Saturday). "Interplanetary Orbits," by Dr. J. G. Porter, to the Society, at Caxton Hall, at 6 p.m.

February 12, 1951 (Monday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to Putney Young Conservatives, S.W.15.

February 17, 1951 (Saturday). "The Design of Rocket Motors," by J. Humphries, to the North-Western Branch, at 49, Lower Mosley Street, Manchester, 2, at 7 p.m.

February 22, 1951 (Thursday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the Isle of Wight Branch of the Royal Aeronautical Society.

March 3, 1951 (Saturday). "Combustion in the Rocket Motor," by Professor A. D. Baxter, to the Society, at Caxton Hall, at 6 p.m.

March 16, 1951 (Friday). "Rocket Propulsion and Interplanetary Flight," by A. V. Cleaver, to the College of Aeronautics, Cranfield, Bletchley, Bucks.

April 6th, 1951 (Friday). "The Application of Rocket Propulsion to Aeronautics and Astronautics," by J. Humphries, to the Society of Licensed Aircraft Engineers (Bournemouth Branch), Christchurch Secondary Modern School, Stourbank Road, Christchurch, at 7.30 p.m.

April 13, 1951 (Friday). "Rockets and Interplanetary Flight," by J. Humphries, to the Royal Aeronautical Society, Leicester Branch, at 7.15 p.m.

May 10, 1951 (Thursday). "Rockets and Interplanetary Flight," by J. Humphries, to the Incorporated Plant Engineers at Royal Turk's Head Hotel, Newcastle-upon-Tyne, at 7.30 p.m.

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